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Protection privée des droits de propriété et ressources naturelles : régimes d'exploitation, frontières et commerce international

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Thèse présentée à la Faculté des études supérieures
en vue de l'obtention du grade de
PhilosophiæDoctor (Ph.D.)
en sciences économiques

Novembre, 1998

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Faculté des études Supérieures
Grade octroyé
à compter du
FEV 4 1999
Université de Montréal

Université de Montréal
Faculté des études supérieures

Cette thèse intitulée:

Protection privée des droits de propriété et ressources naturelles : régimes d'exploitation, frontières et commerce international

présentée par:

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a été évaluée par un jury composé des personnes suivantes:

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Thèse acceptée le : 18 décembre 1998

Sommaire

Il est fréquent d'entendre dire que le manque de droits de propriété bien définis constitue l'une des causes principales de la surexploitation des ressources naturelles dans les pays en voie de développement. Cette étude se veut une contribution à notre compréhension de ce phénomène.

De l'approche proposée dans cette étude, il ressort que la présence d'un accès libre à un site de ressources naturelles peut s'expliquer de manière endogène. C'est-à-dire que le propriétaire légitime d'un site peut trouver préférable de ne pas s'engager à en revendiquer la propriété, ou bien à tenter d'en exclure des empiéteurs.

En effet, on démontre qu'il peut être trop coûteux d'enclore un site de ressources naturelles lorsque les revenus des individus dans une économie sont bas. De plus, même si un site de ressources naturelles est enclos, cela n'empêche pas qu'il soit exploité à un niveau tel que le coût social des ressources récoltées soit plus élevé que leur prix.

Parfois le problème de l'exploitant d'un site ne consiste pas à en exclure les empiéteurs, mais plutôt à en revendiquer la propriété afin d'éviter de se faire évincer. Ce problème est particulièrement présent dans les régions frontières situées loin des centres urbains et administratifs. Un jeu d'appropriation de la terre entre son propriétaire légitime et un contestant est alors proposé. Il est montré comment un propriétaire, au lieu de défendre sa propriété, peut parfois choisir de l'exploiter de manière effrénée. De plus, une baisse du taux d'actualisation peut mener à une utilisation plus abusive de la ressource.

Lorsqu'un pays en voie de développement s'ouvre au commerce international, le libre échange conduit généralement à une hausse du prix des ressources naturelles. Il est montré que cela peut provoquer un changement de régime dans l'exploitation des ressources naturelles, qui passera du libre-accès à la propriété privée. Bien que cela contribue parfois à relâcher la pression sur les ressources naturelles, le bien-être des individus peut se détériorer. Un résultat similaire est obtenu même lorsque les ressources sont soumises à un régime de propriété privée avec et sans libre-échange.

Mots clefs: droits de propriété; coûts de protection; ressources naturelles; niveaux de revenus; développement économique; commerce international; frontières; conflits; dégradation des ressources; compétition pour la terre; forêsts tropicales

Abstract

This thesis considers problems of natural-resource exploitation when property rights are costly to enforce. To novelty of the approach consists mainly in the endogenization of these costs by explicitly deriving individuals' incentives to encroach, or to contest others' claims to ownership.

The first chapter proposes a model of natural resource exploitation when private ownership requires costly enforcement activities. For a given wage rate, it is shown how enforcement costs can increase with labor's average productivity on a resource site. As a result, it is never optimal for the site owner to produce at the point where marginal productivity equals the wage rate. It may even be optimal to exploit at a point exhibiting negative marginal returns. An important parameter in the analysis is the prevailing wage rate. When wages are low, further decreases in the wage rates can reduce the returns from resource exploitation. At sufficiently low wages, positive returns can be rendered impossible to achieve and the site is abandoned to free access exploitation. The analysis provides some clues as to why property rights may be more difficult to delineate in less developed countries. It proposes a different framework from which to address normative issues such as the desirability of free trade with endogenous enforcement costs, the optimality of private decisions to enforce property rights, the effect of income distribution on property rights enforceability, etc.

In the second chapter, competition for land at the frontier is analyzed by considering a game between a first settler and a contestant. Although the first settler is the legitimate owner of a plot of land, the fact that it is located far from the government's administrative centers makes it difficult to prove his claim. This creates incentives for a contestant to dispute his claims and attempt to evict him. Both contenders will expend resources in order to secure ownership. The model accounts for the fact that the more remote is a plot of land, the lower will be the land's output value due to transport costs; this tends to discourage appropriation activities. The analysis suggests that many scenarios are possible as the distance from the centers increases, depending on some parameter values. In one scenario, conflicts over property rights will take place at intermediate distances from the center. In other scenarios, land degradation may be used as a substitute to appropriation activities, thereby eliminating incentives for a conflict. It is shown that a reduction in the discount rate may encourage land degradation.

The third chapter proposes a general-equilibrium model with endogenous tenure regimes in the natural-resource sector. Tenure regimes, i.e. free access vs private property, are endogenized through the introduction of an endogenous enforcement-cost function, which is itself derived from individuals' incentives to encroach. It is shown that in autarky, at low levels of capital endowments, a free-access regime in the resource sector may hold. A move to free trade, with a higher resource price, may induce a shift to private property in the resource sector, which is accompanied by a reduction in the intensity of resource exploitation. However, this shift of tenure regime may be welfare decreasing. Furthermore, at higher levels of capital endowments, a private-property tenure regime may result in equilibrium in both autarky and free trade. And even though private property prevails with and without trade, trade may still be welfare decreasing.

Keywords: property rights; enforcement costs; natural resources; income levels; economic development; international trade; frontier; conflicts; land degradation; land competition; tropical forests

Résumé

Ce travail traite du problème d'exploitation des ressources naturelles lorsque les droits de propriété sont coûteux à faire respecter. L'approche proposée tire son originalité principalement de ce que les coûts de protection de la propriété y soient déterminés de manière endogène. Pour ce faire, on tient compte des inclinations des individus à violer la propriété d'autrui. Le détenteur d'un droit de propriété devra dès lors décider s'il désire toujours le faire respecter et quelles dépenses y consacrer, le cas échéant. C'est à partir de ce cadre d'analyse que découlent les principales contributions de cette thèse. Nous verrons que l'étude sera particulièrement pertinente pour les pays en voie de développement.

Une implication majeure de l'analyse consiste en la proposition que l'exploitation intensive des ressources naturelles peut être utilisée comme substitut aux activités de protection des droits de propriété. En effet, il est raisonnable de supposer qu'à partir d'un certain seuil, l'usage plus intensif d'une ressource en réduit la valeur. Il en résulte une diminution dans le rendement des activités d'empiètement, ou de contestation des droits de propriété, permettant ainsi d'économiser sur les activités de protection de la propriété. Nous verrons comment cet arbitrage entre coûts de protection des droits de propriété et exploitation modérée des ressources naturelles peut mener à des effets inattendus. Ces effets feront suite à des varia-

tions exogènes de prix dans le cas d'un équilibre partiel ou du passage de l'autarcie au libre-échange dans le cas d'un équilibre général.

Deux cas d'équilibre partiel sont considérés. Le premier s'applique à celui d'une ressource renouvelable en état stationnaire, où le prix de la ressource et le niveau des salaires sont fixés de manière exogènes. En supposant la présence d'un grand nombre d'empiéteurs potentiels, il est démontré que dans un équilibre avec propriété privée,[1] le revendicateur d'une ressource fera en sorte qu'aucun de ceux-là n'aura intérêt à violer sa propriété. Afin de dissuader l'empiètement, un propriétaire aura recours à deux moyens : d'une part, il engagera des dépenses afin d'augmenter la probabilité de détecter un empiéteur et d'autre part, il exploitera sa ressource de manière plus intensive que ce qui serait souhaitable sans le problème d'empiètement. Dans certains cas, il est même admissible que le propriétaire d'une ressource choisisse d'engager des travailleurs à un niveau tel qu'ils aient une productivité marginale négative.

L'étude démontre de plus qu'il existe un seuil dans le niveau des salaires au-dessous duquel les coûts reliés à l'exclusion des empiéteurs sont si élevés que la propriété privée n'est plus rentable ; on obtient alors un équilibre où les ressources sont soumises à un accès libre. Ce résultat découle du fait qu'avec de bas salaires, le coût d'opportunité du loisir peut s'avérer si bas que les individus sont fortement enclins à consacrer une part importante de leur temps libre à empiéter sur la propriété d'autrui, leur permettant ainsi de hausser leur revenu. Un propriétaire de ressource ne peut alors contenir les empiéteurs sans encourir des pertes d'exploitation. Il décidera alors d'abandonner son site. Ce résultat pourrait ex-

[1] Notons que par "propriété privée", nous entendons ici un site de ressources naturelles qui a été enclos et dont le propriétaire peut légitimement tenter d'exclure des empiéteurs. L'expression est donc utilisée par opposition à un régime d'exploitation de libre-accès.

pliquer la présence plus répandue de ressources exploitées en libre-accès dans les pays en voie de développement. On y démontre également qu'une hausse du prix de la ressource peut contribuer à promouvoir la propriété privée, réduisant ainsi l'intensité de son exploitation. Nous verrons que cet effet jouera un rôle essentiel dans l'étude du commerce international avec droits de propriété endogènes.

Le second cas d'équilibre partiel est motivé par le problème de la dégradation des ressources naturelles dans certaines régions de forêts tropicales. Ces endroits étant souvent éloignées des centres administratifs gouvernementaux, les droits de propriété sur la terre y sont parfois difficile à définir. Ceci découle du fait que sans la proximité d'un appareil judiciaire, les efforts de définition des droits de propriété peuvent s'avérer inefficaces. S'il appert que le réclamant légitime d'une terre aura du mal à prouver ses droits, certains individus seront incités à lui en contester la propriété.

Un jeu est proposé dans lequel un contestant peut engager des dépenses afin d'évincer le propriétaire légitime d'une terre. Ces dépenses auront d'autant plus de succès que ce propriétaire emploie peu de moyens pour faire reconnaître ses droits de propriété. À son tour, ce dernier pourra tenter de diminuer la probabilité d'une éviction en dépensant plus pour affermir ses droits. Cependant, et de manière similaire au cas précédent, l'exploitant peut avoir recours à un autre moyen de profiter de la valeur productive de sa terre, moyen qui lui fera économiser dans ses coûts de revendication : il peut en épuiser rapidement le stock de ressources de manière à en retirer un gain de court terme. Lorsque la valeur productive de la terre sera complètement dégradée, il n'y aura plus lieu d'en réclamer la propriété, d'où l'économie.

Les fonctions de réaction pour le contestant et le propriétaire légitime sont dérivées. On y détermine le niveau des dépenses d'appropriation de chacun des adversaires à l'équilibre. Ceci nous permet d'analyser ce qui se passe à mesure que la distance entre un lopin de terre et la ville augmente. Deux effets exogènes dus à l'éloignement de la ville sont introduits : en premier lieu, plus une terre est loin de la ville et de ses marchés, plus le prix de la ressource produite sera bas car on devra en déduire les coûts de transport; en second lieu, la distance augmentera, ceteris paribus, les chances de succès du contestant dans ses tentatives d'éviction de l'exploitant actuel. À l'équilibre, plusieurs scénarios sont possibles.

Dans un scénario, les terres sont exploitées de manière durable[2] à proximité des villes et les droits de propriété des exploitants y sont bien définis, selon le sens suivant : étant données les dépenses de reconnaissance des droits de propriété d'un propriétaire actuel, un contestant n'a pas intérêt à tenter de lui disputer sa revendication. Cela est dû au fait qu'à proximité de la ville, la forte présence de l'appareil judiciaire permet aux propriétaires des terres de prouver facilement leur réclamation. Il n'y aura donc aucun conflit. L'équilibre avec absence de conflit et exploitation durable de la terre est également obtenu pour de très grandes distances de la ville. Dans ces cas, cepandant, le contestant perd tout intérêt à s'engager dans un conflit non pas grâce à la forte présence d'un appareil judiciaire, mais plutôt à cause de la faible valeur de la ressource produite. Les choses se gâtent, cependant, entre ces deux extrêmes. L'analyse démontre que pour certains scénarios, à des distances intermédiaires, le prix de la ressource peut être encore assez élevé pour justifier des activités de contestation. Le propriétaire peut toutefois avoir du mal à faire reconnaître sa propriété parce que la

[2] Par "exploitation durable", nous entendons une utilisation de la terre qui produira un niveau d'output constant, soutenu indéfiniment. L'expression fait opposition à une utilisation non durable, auquel cas le niveau d'output deviendra nul, suite à un épuisement du stock de la ressource.

présence d'un appareil judiciaire y est moins importante. Dans certains cas, il y aura conflit. C'est-à-dire que la ressource sera exploitée de manière durable mais que le propriétaire dépensera afin de défendre ses droits, tandis que le contestant tentera de l'évincer. Dans d'autres cas, il n'y aura pas de conflit mais la ressource sera utilisée de manière non durable. C'est-à-dire qu'au lieu de défendre sa propriété, l'exploitant décidera de bénéficier du gain de court terme que lui procure un épuisement rapide de son stock productif. On assiste alors à une dégradation des ressources naturelles.

Il est également montré qu'une baisse du taux d'intérêt peut, dans certains cas, contribuer à encourager l'utilisation non durable d'une ressource. Ce résultat contre-intuitif provient du fait qu'avec une baisse du taux d'intérêt, la valeur d'un usage de long terme d'une ressource augmente. Bien que ceci encourage l'exploitant à dépenser plus pour affermir sa propriété, le contestant est également incité à intensifier ses activités d'appropriation. Dans certains cas, il est montré que le second effet peut l'emporter sur le premier et que l'exploitant décide, avec un taux d'intérêt plus bas, d'épuiser rapidement le stock de la ressource.

Le modèle proposé dans le premier cas d'équilibre partiel est ensuite introduit dans un cadre d'équilibre général. Cela permet d'étudier certains effets de l'ouverture au libre-échange sur le bien-être, sur l'intensité d'exploitation des ressources naturelles, ainsi que sur le régime d'exploitation à l'équilibre. On y démontre en premier lieu qu'une hausse du stock de capital physique dans une économie peut encourager le recours à la propriété privée dans l'exploitation des ressources naturelles. Cela provient du fait qu'avec un stock de capital plus élevé, les salaires des travailleurs peuvent augmenter, haussant alors le coût d'opportunité de leurs temps libres. Ces derniers auront alors moins d'incitation à empiéter sur la propriété d'autrui, rendant ainsi la propriété privée moins coûteuse à protéger.

Tel qu'on s'y attendrait, une fois que les ressources naturelles d'une économie auront été encloses, on assistera parfois à une réduction dans l'intensité de leur exploitation. Toutefois, même si les ressources étaient exploitées de manière abusive en libre-accès, ce recours à la propriété privée n'améliore pas nécessairement le bien-être des individus dans l'économie. Ceci est dû à la nécessité d'engager des dépenses nécessaires à l'exclusion des empiéteurs, dépenses qui n'existaient pas en régime de libre-accès. Ces dernières peuvent parfois être assez importantes qu'elles outrepassent les gains résultant d'une utilisation plus retenue des ressources naturelles.

De manière similaire, on observe que le commerce international peut provoquer un passage à la propriété privé lorsqu'il induit une hausse du prix de la ressource, ce qui est souvent le cas pour un pays en voie de développement. Mais encore une fois et pour les mêmes raisons, ce passage n'améliore pas nécessairement le bien-être des individus, même si les ressources naturelles s'en trouvent exploitées de manière moins effrénée. Rappelons que le modèle proposé permet d'endogénéiser le régime d'exploitation des ressources naturelles. Il offre ainsi une interprétation différente de certaines études récentes sur les effets de l'ouverture au commerce international, ces dernières prenant comme donné le régime d'exploitation en libre-accès dans les pays en voie de développement, avant et après cette ouverture.

L'étude révèle de plus que même si un régime de propriété privée règne à l'équilibre avant et après l'ouverture au commerce international, cette ouverture peut s'avérer néfaste pour le bien-être des individus. Car même si les ressources sont soumises à un régime de propriété privée, cela n'empêche pas qu'elles soient exploitées à un niveau tel que leur coût social excède leur prix ; cela afin de réduire les coûts d'exclusion des empiéteurs. Il se crée alors une distorsion dans les prix, faisant en sorte que le commerce international ne soit pas nécessairement désirable.

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à la mémoire de Lucius Hotte, mon père

Remerciements

Cette thèse a vraiment commencé un soir de mars 1993, alors qu'Ana et moi célébrions notre second anniversaire de marriage dans un bistrot de la rue Bernard. Entre deux gorgées de vin – faut-il le préciser – elle m'a lancé : "Si c'est vraiment ce que tu désires faire, fais-le. Tu auras mon appui." Son appui, il n'a jamais faibli et je le reçois encore au moment où j'écris ces lignes. Sache, Ana, que durant chacune de ces longues soirées de travail passées à l'université, je n'ai jamais cessé de penser à toi. Gracias.

Je suis également endetté envers Diego qui, malgré lui, a bien souffert de cette thèse. J'espère pouvoir te le remettre.

On dit parfois que le rôle d'un bon directeur de recherche consiste à bien baliser les efforts de l'étudiant. Le professeur Gérard Gaudet a accompli bien plus que cela. Il a cherché à m'inculquer son approche rigoureuse et son souci de la perfection dans l'exécution de mon travail. Je ne sais s'il y est parvenu, mais la confiance qu'il m'a accordée m'a certainement permis de mieux croire en mon travail. Cela aura des effets qui se feront sentir bien au-delà de cette thèse. Je ne l'oublierai jamais.

Si j'ai pu continuer à travailler dans le domaine de l'économie du développement, sujet qui me passionne en premier lieu, je le dois entièrement au professeur André Martens. Sans son appui du tout début, j'aurais certainement dû y renoncer. Je tiens aussi à remercier le Professeur Jean Mercenier pour ses bons conseils et encouragements dans les moments critiques. Son support moral me fut indispensable.

Je suis reconnaissant envers le programme PARADI, le CRSH, ainsi que le CRDE pour leur aide financière.

J'aimerais remercier mes collègues et amis qui ont été particulièrement présents dans mon entourage et qui ont rendu le voyage plus agréable. Il s'agit de Stéphan Ambec, Carlos Avilés, Jean Farès, Karine Gobert, Norma Khozaya, Fethi Mili, Olivier Torrès, Christian Tritten et Lars Vilhuber.

Introduction générale

Le manque de clarté dans l'attribution droits de propriété est souvent considéré comme l'une des causes principales de la surexploitation des ressources naturelles dans les pays en voie de développement.[3] Cette étude se veut une contribution à notre compréhension de ce phénomène. Nous tenterons de répondre, entre autre, aux deux questions suivantes : Pourquoi les droits de propriété sont-ils mal définis? Pourquoi le problème semble-il plus répandu dans les pays en voie de développement?

Plusieurs auteurs ont déjà proposé des explications quant au choix entre l'accès libre et la propriété privée en tant que régime d'exploitation.[4] Certains argumentent que cela peut être le fait d'institutions exogènes tels que des facteurs culturels, la religion, l'appareil judiciaire, etc.[5] D'autres y vient plutôt le résultat d'une comparaison entre coûts et bénéfices de la propriété privée. En effet, s'il est coûteux d'enclore une propriété, on ne revendiquera ses droits que si les bénéfices en dépassent les coûts.[6] Bien que chacune de ces études nous permet de mieux saisir certains aspects du choix d'un régime d'exploitation, aucune ne permet

[3] World Bank (1992).

[4] Notons que par "propriété privée", nous entendons ici un site de ressources naturelles qui a été enclos et dont le ou les propriétaires peuvent légitimement tenter d'exclure des empiéteurs. L'expression est donc utilisée par opposition à un régime d'exploitation de libre-accès.

[5] Voir, entre autres, North (1990), Cohen et Weitzman (1975) et Firmin-Sellers (1995).

[6] Anderson et Hill (1975) et Field (1989).

d'expliquer les différences observées entre pays à hauts et bas revenus. Cette étude en propose une.

Un cadre d'analyse sera proposé où le choix d'enclore un site de ressources naturelles, ou d'en revendiquer la propriété, est également le résultat d'une comparaison entre ses bénéfices et ses coûts. L'approche proposée tire son originalité principalement de ce que les coûts de protection de la propriété y soient déterminés de manière endogène. Pour ce faire, on tient compte des inclinations des individus à violer la propriété d'autrui. Le détenteur d'un droit de propriété devra dès lors décider s'il désire toujours le faire respecter et quelles dépenses y consacrer, le cas échéant.

Une implication majeure de l'analyse consiste en la proposition que l'exploitation intensive des ressources naturelles peut être utilisée comme substitut aux activités de protection des droits de propriété. En effet, il est raisonnable de supposer qu'à partir d'un certain seuil, l'usage plus intensif d'une ressource en réduit la valeur. Il en résulte une diminution dans le rendement des activités d'empiètement, ou de contestation des droits de propriété, permettant ainsi d'économiser sur les activités de protection de la propriété. Nous verrons comment cet arbitrage entre coûts de protection des droits de propriété et exploitation modérée des ressources naturelles peut mener à des effets inattendus.

Dans le premier chapitre de cette thèse, on propose une formalisation du problème d'exploitation d'un site d'une ressource naturelle renouvelable dans un cadre d'équilibre partiel. Le propriétaire du site doit décider de l'intensité de son exploitation ainsi que des dépenses qu'il doit consacrer aux fins d'exclusion des empiéteurs. Il peut aussi décider d'abandonner le site à un régime d'accès libre. Le cas d'un équilibre stationnaire du stock de la ressource est considéré où le prix de la ressource et le taux de salaire sont fixes. En supposant la présence d'un grand nombre d'empiéteurs potentiels, il est démontré que dans un équilibre avec propriété privée, le propriétaire d'un site fera en sorte qu'aucun de ceux-là n'ait intérêt à violer sa propriété. Afin de dissuader l'empiètement, un propriétaire aura recours à deux moyens : d'une part, il engagera des dépenses afin d'augmenter la probabilité de détecter un empiéteur et d'autre part, il exploitera sa ressource de manière plus intensive que ce qui serait souhaitable sans le problème d'empiètement. Dans certains cas, il est même admissible que le propriétaire d'une ressource choisisse d'engager des travailleurs à un niveau tel que leur productivité marginale dans l'exploitation de la ressource soit négative.

L'étude démontre de plus qu'il existe un seuil dans le niveau des salaires en deçà duquel les coûts reliés à l'exclusion des empiéteurs sont si élevés que la propriété privée n'est plus rentable ; on obtient alors un équilibre où les ressources sont soumises à un accès libre. Ce résultat découle du fait qu'avec de bas salaires, le coût d'opportunité du loisir peut s'avérer si bas que les individus sont fortement enclins à consacrer une part importante de leur temps libre à empiéter sur la propriété d'autrui, leur permettant ainsi de hausser leur revenu. Un propriétaire de ressource ne peut alors contenir les empiéteurs sans encourir des pertes d'exploitation. Il décidera alors d'abandonner son site. Ce résultat pourrait expliquer la présence plus répandue de ressources exploitées en libre-accès dans les pays en voie de développement. On y démontre également qu'une hausse du prix de la ressource peut contribuer à promouvoir la propriété privée, réduisant ainsi l'intensité de son exploitation.

Le second chapitre se penche sur les problèmes de dégradation des ressources naturelles dans certaines régions de forêts tropicales. Ces endroits étant souvent éloignés des centres administratifs gouvernementaux, il est parfois difficile d'y bien définir les droits de propriété sur la terre. Cette situation encourage la compétition pour la terre.[7] Mais elle incite aussi à l'utilisation non-durable de la terre.[8] Jusqu'à présent, aucune étude n'avait tenté de formaliser le choix d'un propriétaire terrien entre une utilisation durable et non-durable de la terre, tout en prenant en compte les dépenses de revendication de la propriété et les incitations d'une autre partie à la contester. Une telle formalisation est proposée dans le second chapitre.

S'il appert que le réclamant légitime d'une terre aura du mal à prouver ses droits, certains individus seront incités à lui en contester la propriété. Un jeu est proposé dans lequel un contestant peut engager des dépenses afin d'évincer le propriétaire légitime d'une terre. Ces dépenses auront d'autant plus de succès que ce propriétaire emploie peu de moyens pour faire reconnaître ses droits de propriété. À son tour, ce dernier pourra tenter de diminuer la probabilité d'une éviction en dépensant plus pour affermir ses droits. L'exploitant peut cependant avoir recours à un autre moyen de profiter de la valeur productive de sa terre, moyen qui lui fera économiser dans ses coûts de revendication : il peut en épuiser rapidement le stock de ressources de manière à en retirer un gain de court terme. Lorsque la valeur productive de la terre sera complètement dégradée, il n'y aura plus lieu d'en réclamer la propriété, d'où l'économie.

L'analyse prend en compte le fait quà mesure que l'on s'éloigne des centres urbains, le prix de la ressource produite sur la terre diminue à cause des coûts de transport. D'autre part, il devient plus difficile, pour un propriétaire, de définir ses droits de propriété car la présence d'un l'appareil judiciaire s'amenuise. Il est montré qu'à proximité des centres urbains, le propriétaire d'une terre se protégera

[7]Dans le cas de l'Amazonie, on peut consulter les ouvrages de Bunker (1985) et de Schmink et Wood (1992). Pour des exemples en Amérique Centrale et aux Philippines, voir Cruz, Meyer, Repetto et Woodward (1992). Dejene et Olivares (1991) rapportent sur la situation au Mozambique.

[8]Ceci est rapporté, entre autre, par Schneider (1995), Dorner et Thiesenhuesen (1992) et Cruz, Meyer, Repetto et Woodward (1992).

de manière à décourager complètement les efforts d'éviction d'un contestant potentiel. Cela est dû au fait qu'à proximité de la ville, la forte présence de l'appareil judiciaire permet aux propriétaires de prouver facilement leur réclamation. Il n'y aura aucun conflit et la terre sera utilisée de manière durable. Il en sera de même pour les terres situées à de très grandes distances des centres et cela à cause des coûts de transport élevés qui rendent le prix de la ressource trop faible pour justifier une contestation. Entre ces deux extrêmes, c'est-à-dire pour des distances intermédiaires, le modèle indique que plusieurs scénarios sont possibles selon les paramètres. Dans un cas, la terre sera utilisée de manière durable mais il y aura conflit. Dans un autre cas, il n'y aura pas de conflit mais la terre sera utilisée de manière non durable.

Il est également montré qu'une baisse du taux d'intérêt peut, dans certains cas, contribuer à encourager l'utilisation non durable d'une ressource. Ce résultat contre-intuitif provient du fait qu'avec une baisse du taux d'intérêt, la valeur d'un usage de long terme d'une ressource augmente. Bien que cela encourage l'exploitant à dépenser plus pour affermir sa propriété, le contestant est également incité à intensifier ses activités d'appropriation. Dans certains cas, il est montré que le second effet peut l'emporter sur le premier et que l'exploitant décide, avec un taux d'intérêt plus bas, d'épuiser rapidement le stock de la ressource.

Dans le troisième chapitre, un modèle d'équilibre général avec régime d'exploitation endogène est proposé. On utilise le modèle développé au premier chapitre afin de représenter les incitations à enclore un site de ressources naturelles. Cette approche nous permet d'endogénéiser les régimes d'exploitation des ressources naturelles ainsi que les coûts de protection de la propriété privée. Appliqué à l'étude de certains effets du commerce international, cela conduit à des interprétations différentes de celles proposés par des études récentes tels que Chichilnisky (1994), Brander et Taylor (1997a, 1997b, 1998) ou Tornell et Velasco (1992). Ces derniers ont analysé certains effets du commerce international en prenant comme donné le régime d'accès libre dans les régions en voie de développement. Le modèle proposé au troisième chapitre suggère que lorsque le régime d'exploitation est choisi de manière endogène, le commerce international peut avoir des effets non prévus dans les études existantes. Par exemple, pour une petite économie ouverte, l'ouverture au commerce international peut aider à réduire l'intensité d'exploitation des ressources naturelles même si le prix de la ressource augmente. Cela est dû au fait qu'un prix plus élevé de la ressource peut induire un passage du libre-accès à la propriété privée dans l'exploitation des ressources. Mais le bien-être des individus ne s'en trouve pas nécessairement amélioré car ce passage fait apparaître des coûts de protection de la propriété privée qui étaient inexistants en régime d'accès libre. En d'autre mots, le libre-échange, en encourageant la propriété privée, peut faire balancer une économie dans un régime où il y a plus de propriété privée que ce qui serait efficace. Notons que De Meza et Gould (1992) ont déjà observé qu'en équilibre général, il existe des équilibres avec propriété privée qui sont inefficaces.

Il est également montré que même si un régime de propriété privée règne à l'équilibre avant et après l'ouverture au commerce international, cette ouverture peut s'avérer néfaste pour le bien-être des individus. Car même si les ressources sont soumises à un régime de propriété privée, cela n'empêche pas qu'elles soient exploitées à un niveau tel que leur coût social excède leur prix ; cela afin de réduire les coûts d'exclusion des empiéteurs. Il se crée alors une distorsion dans les prix, faisant en sorte que le commerce international ne soit pas nécessairement désirable.

Chapitre 1

Natural-Resource Exploitation with Costly Enforcement of Property Rights

1.1 Introduction

Ill-defined property rights are often cited as a major cause underlying the inefficient exploitation of natural resources. Although present in both industrialized and less developed countries, the problem seems to be more accute in the latter[1]. This begs the question not only as to why property rights may be deficient on some natural resource sites[2], but also as to why it seems more difficult to protect those rights in less developed economies.

Observing that property rights are not as well defined in less developed countries, a few theoretical inquiries have considered the effects of trade between industrialized regions with well defined property rights and less industrialized regions

[1]World Bank (1992, Chapter 3).

[2]For the present purpose, the expression *natural resource site* is meant to apply mostly to renewable resources such as inshore fisheries, pasture lands, forests, irrigation systems, hunting territories, etc., evolving in a steady-state (see Gordon (1954) for instance). I therefore abstract from any dynamic considerations such as the nonrenewability of a resource or out of steady-state behavior.

with deficient property rights (see, e.g., Chichilnisky 1994; Brander and Taylor [1997, 1998]; Tornell and Velasco 1992). These studies take tenure regimes in both regions as exogenous to the analysis. In this respect, a more fundamental issue is being sidesteped which may affect some of their conclusions about the effects of trade: they do not account for the causes of the different prevailing tenure regimes.

Another branch of the literature on property rights offers various reasons explaining the different tenure regimes in effect accross regions or periods. Some authors contend that it may be related to a society's culture, religion, legal institutions, etc. (North 1990; Cohen and Weitzman 1975; Firmin-Sellers 1995). Others have suggested that securing those rights be the result of a cost-benefit analysis on the part of the private owner. If there are costs associated with property enclosure, ownership will be claimed only as long as benefits from exploitation exceed enclosure costs. Anderson and Hill (1975) advocate such economic incentives underlying the determination of property rights. In their formulation, enclosure movements are mostly driven by exogenous technological progress in enforcement technology and by changes in output prices. Within the context of an open international economy, their analysis, however, can hardly account for the differences in property rights regimes observed between industrialized and less developed economies. Field's (1989) approach gets closer to providing an explanation by observing that an increase in population can lead to a reduction in exclusion costs through the increased supply of labor. Unfortunately, he does not provide us with a complete analytical framework. What is needed, therefore, is a theoretical framework which, based on economic incentives, provides clues as to why it seems more difficult to claim ownership over natural resource sites in less developed countries. The present study proposes one.

As mentioned above, one of the principal impediments for the delineation of property rights resides in the often too large costs of enforcement. An individual who holds a title to a resource site must decide whether to engage in costly enforcement activities in order to exclude potential encroachers. This analysis attempts to determine which factors may affect these costs.

Accepting that well defined property rights require the costly activity of excluding encroachers, one can assume that the higher the incentives to encroach, the costlier it is to exclude. My analysis borrows from the literature on the economics of crime and the supply of illegal labor in order to pin down an individual's incentives to encroach. This leads to the determination of an enforcement cost function for a resource site, according to which enforcement costs are positively related to the value of average product of labor on the site, but negatively related to the prevailing legal wage rate in the economy.

The proposed enforcement cost function enters the profit function of the holder of the title to a site. I show that under reasonable assumptions regarding the functional forms of both the production and detection functions, rents from a resource site exploitation may actually decrease following a reduction in the legal wage rate. Moreover, there exists a positive threshold level of the wage rate for which further reductions in its value make it prohibitively expensive to protect one's property from encroachment. This suggests a strictly economic rationale for the lack of well defined property rights observed in low income or pre-industrial economies, which differs from other oft-mentioned non-economic factors such as differences in technology, culture, legal institutions, etc. The model also allows us to verify Demsetz's (1967) conjecture which states that an increase in resource value is likely to lead to better delineated property rights.

The paper is organised as follows: Section 1.2 determines the general shape and arguments of an enforcement cost function for the definition of property rights on a natural resource site; partial equilibrium exploitation decisions for a profit maximizing resource site owner are then derived. The effects of varying the legal wage rate on the profit function are presented in Section 1.3. In Section 1.4, I consider the effects of increasing the resource price on the delineation of property rights. The conclusion presents a discussion of the results and proposes some extensions.

1.2 The Model

In this section, a model will be developed which leads to an enforcement cost function for the delineation of property rights over the exploitation of a resource site. In order for property rights over a resource site to be *well defined*, it must be the case that the holder of those rights, the owner, receive all the benefits from its exploitation and bear all the costs. These costs take the form of direct exploitation costs, but must also include the costs involved in enforcing property rights, i.e. ensuring that no one will encroach on the property. It must be emphasized that the fact that nobody encroaches on the property does not imply that enforcement activities are absent; to the contrary, it implies that these activities are important enough to completely discourage any desire to encroach. I do not exclude, however, the possibility of *partially defined* property rights, in which case the owner could consider that it is in her own best interest, given the costs of excluding encroachers, to let a certain amount of the site's output be captured by encroachers. We will see below, however, that in the proposed model, a profit maximizing site owner will never opt to partially define her property rights[3]; she either completely eliminates all incentives to encroach or, if enforcement costs are too large, she abandons the site to a free access exploitation. Note that in this last case, the institution of private property will not be sufficient to prevent free access from occuring in equilibrium. Moreover, private decisions to have well defined property rights may not be a socially efficient outcome as there are now costs involved in defining property rights[4].

Consider now the following model of natural resource exploitation with costly enforcement of property rights. Assume a community inhabited by a total of N *workers* and a certain number of *owners*, which may comprise natural resource site owners as well as any other type of productive capital ownership. All workers receive a legal wage from a job they hold in the official or legitimate sector, which includes employment by a resource site owner who hires workers and pays them the going wage rate. Workers must, however, allocate their spare time *after* official working hours, between leisure and illegal activities[5]. The latter takes the form of encroachment over a resource site. Workers are assumed to be consumers as well, thus facing a trade-off between consumption levels and leisure time.

Of interest to us is the behavior of the owner who holds a title to a resource site. In order to maximize returns from the site, she must decide on how many workers to hire at the going legal wage rate for the direct exploitation of the resource, and on how much enforcement activities to undertake in order to discourage encroach-

[3]Instances of partial enforcement appear in Helsley and Strange (1994), Milliman (1986), Sutinen and Anderson (1985) and Clarke et al. (1993). Tietenberg (1996, p. 293) provides a short interpretation.

[4]On the efficiency of private decisions to enforce property rights, see Anderson and Hill (1975), de Meza and Gould (1992), Lasserre (1994) and Field (1989).

[5]See Ehrlich (1973), p. 528, for a discussion of the choice between taking part in both legitimate and illegitimate activities or specializing in one type of activity.

ment. This includes relinquishing the site to a free access exploitation where no enforcement activities take place.

In order to concentrate on the problem faced by the owner of a site, let us consider a partial equilibrium setting in which both the wage rate and the resource price are exogenously determined. The owner and encroachers engage in a sequential game where the owner first chooses the amount of workers, L, to hire on the site and the amount of enforcement expenditures, x, devoted to containing encroachment. In making these choices, she anticipates the encroachers' reaction to them. As will be described below in more details, the amount of enforcement expenditures can reduce encroachment activities by increasing the probability of detecting an encroacher on the site, denoted by $\lambda(x)$. Each worker constitutes a potential encroacher and they all *simultaneously* choose the amount of time to spend encroaching, h_i, $i = 1, ..., N$, after having observed L and x. Note that the workers hired by the site owner are part of the N encroachers but that encroachment activities can only occur after official working hours. All N workers/encroachers are thus identical in that each receives a legal wage, w, prior to deciding on encroachment activities. Note also that due to the assumed large number of potential encroachers, it is considered prohibitively costly for the owner to contract with every single one of them.

Since the owner is the first mover, let us begin by first deriving the encroachers' reaction to the choices of L and x.

The decision to encroach

Workers face a trade-off between consumption levels and leisure time. Borrowing from the literature on the supply of illegal or unofficial labor[6], let us assume that a

[6]For a review and some references, see Cowell (1990, chapter 5).

worker derives utility from both consumption of goods, c, and leisure time, $T - h$, where T is the total amount of leisure time available *after* official working hours, and h denotes time spent on illegal activities. The following simple representation of utility will be used[7]:

$$U(c, h) = c\,(1 - h), \tag{1.1}$$

where T has been normalized to one. Recall that all workers are assumed to be active within the official sector; the only choice variable resides in the amount of time, $0 \leq h \leq 1$, spent on illegal activities after legal working hours. The utility function implies that workers are risk-neutral as far as their consumption levels are concerned[8] and that higher consumption levels increase the opportunity cost of leisure time.

The period of inelastically supplied legal work being normalized to one, legal work brings in a wage w with certainty for that period. Illegal work, which takes the form of encroachment over a resource site, involves an element of uncertainty regarding its return. This is due to the fact that an encroacher, if detected, will be punished. For simplicity, I will assume that punishment carries a monetary value equivalent to a fine which confiscates all illegal income, and that the probability of being detected depends solely on the decision to encroach, regardless of the amount of time spent encroaching. Hence, if the probability of being detected is given by $\lambda(x)$, consumption will be equal to $c_0 = w$ with probability $\lambda(x)$ and to $c_1 = w + hw_{il}$ with probability $1 - \lambda(x)$, where w_{il} represents the return from illegal activities[9]. It is natural to assume that w_{il} is equal to the *value of average product*

[7]Schmidt and Witte (1984, Appendix 9.2) provide a good discussion of the assumptions on a utility function using leisure and consumption as its arguments.

[8]See Block and Heineke (1973) and Cowell (1981) on the supply of labor under income uncertainty.

[9]See Becker (1968), Ehrlich (1973), and Heineke (1978) for similar representations of an individual's decisions to participate in illegitimate activities when there is a probability of apprehen-

(VAP) of labor time on the site[10]. The encroachment problem proposed here is in many respects similar to the problem of free access exploitation developed in Dasgupta and Heal (1979), the main differences being that the opportunity cost of exploiting the resource for the encroacher is given by the value of his leisure time and that the encroacher must face a probability of being fined if detected. The function $\lambda(x)$ will be assumed to satisfy the following properties[11]:

$$\lambda'(x) > 0,\ \lambda''(x) < 0,\ \lambda(0) = 0,\ \lim_{x \to \infty} \lambda(x) = 1,\ \lim_{x \to \infty} \lambda'(x) = 0,\ x \geq 0. \quad (1.2)$$

Let $R(H)$ be the total output function for the resource site, where H denotes the total amount of labor time exploiting the site, i.e. $H = L + \sum_{i=1}^{N} h_i$. Hence, $VAP = VAP(H) = pR(H)/H$, where p is the resource price in units of consumption goods. I will assume that $VAP'(H) < 0$ and that there exists $0 < \bar{H} < \infty$ such that $VAP(\bar{H}) = 0$. Having observed the choice of L and x by the owner of the site, the jth encroacher will maximize his expected utility by choosing h_j, taking as given h_i, $i \neq j$, in order to solve the following problem:

$$\max_{h_j} E[U] = (1 - \lambda(x)) \left[w + h_j VAP(L + \sum_{i \neq j} h_i + h_j) \right] (1 - h_j) + \lambda(x) w (1 - h_j). \quad (1.3)$$

The equilibrium decisions of the encroachers must therefore satisfy, for an interior solution, the following set of first-order conditions for $j = 1, ..., N$:

$$(1 - h_j^*)(1 - \lambda(x))[VAP(H) + h_j^* VAP'(H)] = w + (1 - \lambda(x)) h_j^* VAP(H). \quad (1.4)$$

sion and punishment. In the present model, punishment takes the general form of a proportional fine, $f = \gamma h w_{il}$, with $\gamma = 1$ for simplicity. Any other factor of proportionality would preserve the essence of the results. Lump-sum and infinitely large fines are ruled out; they are believed to be either inefficient or socially unacceptable. See, for instance, Stigler (1970), Friedman and Sjostrom (1993) and Van Rijckeghem and Weder (1997) on the magnitudes of fines.

[10]Productivity differences due to investments or better technology by the owner are assumed away. See Besley (1995) for theory and evidence on property rights and investment incentives.

[11]The analysis does not consider the issue of *third party enforcement* (North 1990, Chapter 7). Once an encroacher has been reported to the authorities by a site owner, he is automatically punished and the amount of the fine goes to the treasury.

The right-hand side of the above relation gives the loss in expected utility due to a marginal reduction in leisure time, i.e. it represents the opportunity cost of leisure time. The left-hand side represents the net gain in expected utility resulting from the change in income. In equilibrium, of course, the marginal gain must equal the marginal loss. Rearranging equation (1.4), we get[12],

$$(1-\lambda(x))[(1-2h_j^*)VAP(H)+(1-h_j^*)h_j^*VAP'(H)]=w. \qquad (1.5)$$

Note that since $VAP(H) \geq 0$ and $VAP'(H) < 0$, we must have $h_j^* < 1/2$ in order for the first-order condition to hold. A symmetrical equilibrium, where $h_i^* = h^*$, for all $i = 1, ..., N$, will satisfy:

$$(1-\lambda(x))[(1-2h^*)VAP(L+Nh^*)+(1-h^*)h^*VAP'(L+Nh^*)]=w. \qquad (1.6)$$

Following Dasgupta and Heal (1979, p. 61), consider now the limiting case where N tends to infinity. It can be verified from (1.6) that there exists a certain $\bar{N} \geq 1$ beyond which h^* is monotone decreasing in N[13]. Suppose then that h^* were to tend to some strictly positive value as N goes to infinity. This would mean that Nh^* becomes infinitely large and therefore $VAP(L+Nh^*) = 0$. The left-hand side of (1.6) would then be strictly negative and the first-order condition could not hold. As a result, it must be the case that as N tends to infinity, Nh^* remains finite and h^* goes to zero. The first-order condition is thus, for sufficiently large N:

$$(1-\lambda(x))VAP(L+Nh^*)=w. \qquad (1.7)$$

[12]Note that the first-order conditions imply: $\partial h_j^*/\partial w < 0$, $\partial h_j^*/\partial \lambda < 0$ and, beyond a certain value of N, $\partial h_j^*/\partial L < 0$. These comparative statics results are consistent with empirical investigations on income-generating illegal activities which state that (Heineke 1978): an increase in the probability of being detected, or in the going wage rate, reduces the individual supply of illegal labor; conversely, a larger return to illegal work, which in this case is equivalent to a reduction in L, has the opposite effect. See also Ehrlich (1973) on this.

[13]It can also be verified that the symmetrical equilibrium is unique and stable. (Varian 1992, p. 287)

In other words, as N becomes sufficiently large, h^* becomes infinitesimally small, with the result that the opportunity cost of leisure time becomes simply equal to w and the expected utility gain from a marginal increase in encroachment time becomes $(1-\lambda(x))VAP(L+Nh^*)$. Note that the fact that h^* is small does not imply that encroachment is not a significant problem for the owner. This is because N is large so that Nh^* could be large. It should be noted also that the model replicates Gordon's (1954) result that for a free access resource, i.e. one where $\lambda(x) = 0$ and $L = 0$, we get $VAP(Nh^*) = w$, i.e. taking into account the opportunity cost of labor, all rents from the site are exhausted when N is sufficiently large[14].

Equation (1.7) determines how much encroachment Nh^* will occur for any choice of L and x by the owner. It is the implicit reaction function of the encroachers that the site owner will take as given in making her decisions.

The decision to exploit and enforce a site

The owner wishes to choose the amount of labor to employ, L, and the amount of enforcement activities or expenditures[15], x, in order to maximize profits,

$$\max_{x,L} \Pi = VAP(L+Nh^*)L - wL - x, \tag{1.8}$$

where Nh^* is given implicitly by equation (1.7). The first-order conditions for this problem are:

$$\frac{\partial \Pi}{\partial L} = VAP(L+Nh^*) - w + VAP'(L+Nh^*)\left(1+\frac{\partial(Nh^*)}{\partial L}\right) = 0, \tag{1.9}$$

[14]The conditions that justify the assumption of period-by-period rent dissipation for a free access common property, as in Gordon (1954), are laid out in Brooks et al. (1996).

[15]In practice, enforcement activities can take the form of direct supervision time by the owner, hired guards which may be paid a preferential wage in order to "buy" their honesty, and some material expenditures.

$$\frac{\partial \Pi}{\partial x} = -1 + VAP'(L + Nh^*)\frac{\partial (Nh^*)}{\partial x} = 0. \tag{1.10}$$

Notice that since h_i cannot be negative, Nh^* is bounded from below by zero. Hence, from (1.7), we get $\partial(Nh^*)/\partial L = -1$ when $Nh^* > 0$, and $\partial(Nh^*)/\partial L = 0$ when $Nh^* = 0$. But since positive profits imply that $VAP - w > 0$, $\partial\Pi/\partial L$ is strictly positive when $Nh^* > 0$ and $\Pi > 0$. As a result, for any given x, L must be such that $Nh^* = 0$ in equilibrium. In other words, if $Nh^* > 0$ and profits are positive, profits can be increased by increasing L. Notice also that once Nh^* is equal to zero, further increases in L cannot be offset by reductions in Nh^*. Therefore, for given x, VAP starts decreasing with increases in L and we get $(1 - \lambda(x))VAP(L) < w$, i.e. the expected utility gain from encroaching becomes strictly smaller than its cost. But this cannot be a profit maximizing equilibrium since x could be reduced until the equality is reestablished, resulting in an increase in profits. Let us denote by E the level of enforcement expenditures that minimizes enforcement costs, while respecting equation (1.7) with $Nh^* = 0$. Therefore, E is given by $\lambda(E) = 1 - w/VAP(L)$, or implicitly by[16]

$$E = E\left(1 - \frac{w}{VAP(L)}\right), \tag{1.11}$$

with $E' > 0$, $E'' > 0$, $E = 0$ when $w = VAP(L)$, and $\lim_{VAP\to\infty} E = \lim_{w\to 0} E = +\infty$. These properties for $E(\cdot)$ are derived from the properties of $\lambda(x)$ assumed in (1.2).

Equation (1.11) defines the implicit relation that must prevail in equilibrium between enforcement expenditures, E, and the value of average product of labor,

[16]Note that the detection probability function used here implies that the available technology does not allow for perfectly enclosed properties. This is in line with Barzel's observation that "fences around orchards are not made to be totally insurmountable." (Barzel 1989, p. 110). But this does not necessarily imply that one cannot deter all theft, contrary to Barzel's assertion in the same paragraph. As the present model implies, if thieves are expected utility maximizing individuals, there will always exist a finite level of protection expenditures which will completely eliminate any incentives for theft.

which itself depends on the quantity L of labor hired on the site. This relation will be referred to as the *enforcement cost function* associated with a privately held natural resource site. This function can now be inserted into the profit function of the owner in order to analyse its impact on exploitation levels and private decisions to secure property rights. For an exogenous resource price, p, and wage rate, w, the profit derived by an owner from a site on which property rights are fully protected from encroachment are now:

$$\Pi = pR(L) - wL - E, \tag{1.12}$$

where $E = E(1 - w/VAP(L))$. Notice how the choice of labor not only affects the direct returns from exploitation, $pR(L) - wL$, but also indirectly affects enforcement costs through its effect on $VAP(L)$. Both values being dependent on the number of workers employed, L constitutes the owner's sole choice variable.

The first-order condition for a profit maximizing interior solution is:

$$R'(L^*) = \frac{w}{p}\left[1 + \frac{E'(\cdot)}{VAP^2}\frac{\partial VAP}{\partial L}\right]. \tag{1.13}$$

Since $\partial VAP/\partial L < 0$, we have $pR'(L^*) < w$. Hence the owner of the site employs labor at a level for which the value of marginal productivity is lower than the wage rate. Note that this result obtains despite the fact that all benefits and costs accrue to the owner of the resource, i.e. no encroachment occurs. Depending on the exact form of the production and enforcement functions, it could even be optimal, given the wage rate and the resource price, for the owner of a site to employ labor with negative marginal productivity.

In order to simplify the analysis and illustrate the results, let us assume a quadratic production function[17], i.e. $R(L) = (A - BL)L$, with $A, B > 0$. Then

[17]Such a functional form is quite common in the study of renewable resources; de Meza and Gould (1992) explicitely use such a form. Brander and Taylor (1997) implicitely use such a

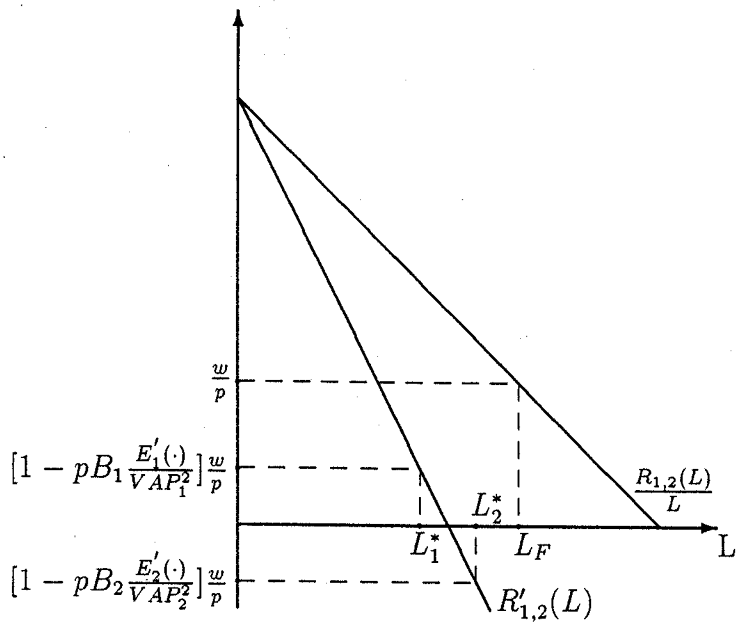

Figure 1.1: Enforcement costs and equilibrium exploitation of a privately owned resource site

$\partial VAP/\partial L = -pB$ and equation (1.13) becomes:

$$R'(L^*) = \frac{w}{p}\left[1 - pB\frac{E'(\cdot)}{VAP^2}\right] \tag{1.14}$$

This result is presented in Figure 1.1, where subscripts 1 and 2 refer to different enforcement and production functions, thus illustrating two possible cases of resource exploitation. L_F refers to the level of exploitation of a free access resource, in which all rents are exhausted, i.e. average product equals the wage rate[18].

function for a ***steady-state*** harvest. Using their notation, it is straightforward to derive their steady-state harvest function as $H^{SS}(L_H) = (\alpha K)L_H - (\alpha^2 K/r)L_H^2$, where K denotes the "carrying capacity" of the resource, r is the "uncongested" growth rate, and α represents a harvest efficiency coefficient.

[18]See Gordon (1954) for an early technical analysis on the exploitation of open access natural resources, Hardin (1968) for an intuitive approach on the "Tragedy of the Commons" or Baumol and Oates (1988, pp. 26-28) for a concise presentation. As mentioned by Ostrom (1990), this theory abstracts from the fact that individuals may organize to improve the efficiency of exploitation of a resource subject to free access. Once a site becomes exploited by an organized group, it can no longer be referred to as free access property but rather as common property. But then this group must devote resources to enforce its exploitation rules and exclude others. In this respect, the site has effectively become enclosed and can be treated as a privately owned site. See also Barzel (1989, p. 71) on this.

The intuition behind the above result is as follows: At the point where the value of labor's marginal productivity equals the wage rate, adding a worker to the exploitation of the resource increases revenues by the same amount as its direct cost, the wage rate. Enforcement expenditures, however, can be reduced since the now lower average productivity makes encroachment less attractive. Therefore, it pays to hire that extra worker. Each further addition to the labor force will yield less than the wage rate and this, at an increasing rate, as there are decreasing returns to labor; conversely, if the gains in reduced enforcement costs occur at a constant or diminishing rate, then an employer will hire more workers until the two effects exactly offset each other. An interior solution for L^* will exist whenever the marginal gain in reduced enforcement costs equals the marginal loss of increased production at a level below L_F. If the marginal enforcement gain and production loss curves do not meet before L_F is reached, then it will never be optimal for an individual to claim ownership over the resource. Note that the existence of an interior solution is not sufficient for the resource site to be privatized; an additional condition is that profits be positive at that point.

We therefore observe that if enforcement costs are positively related to a resource site's value of average productivity of labor, then the level of exploitation will exceed that for which the value of marginal productivity equals the wage rate, even though no encroachment occurs on the site. It is interesting to note that in their study of range land exploitation on Southwestern Indian reservations in the United States, Johnson and Libecap (1980) have observed the use of overgrazing as a means of discouraging potential entrants. They attribute this suboptimal situation to the authorities' refusal to grant formal recognition of land ownership to large herders. The emphasis is thus put on the role of a third party, i.e. the authorities. The foregoing analysis suggests that one should also consider the role played by private decisions to enforce and by incentives to encroach from other individuals on the reservation. Note also that the effectiveness of detection activities could depend on the choice of commodities produced by the owner. This is instanced by Cheung (1970) with the observation that in Tripolitania, more valuable almond production was replaced by cattle raising because almond trees were more difficult to police than cattle which can be driven home at night. In the detection function given by Equation 1.15 below, almond trees would have a higher θ than cattle.

1.3 The Effect of the Wage Rate on the Equilibrium Outcome

The foregoing analysis allows us to perform some comparative static experiments in order to determine the role played by relevant parameters such as an economy's prevailing wage rate or resource price. In order to perform comparative static experiments, let us assume that the function $\lambda(x)$ takes the following form:

$$\lambda(x) = 1 - e^{-x/\theta} \tag{1.15}$$

where θ is a shift parameter. It is easy to verify that this function has the required properties. Substituting $\lambda(x) = \lambda(E) = 1 - w/VAP(L)$ and inverting the function, we find that:

$$E = \theta \ \ln\left(\frac{VAP(L)}{w}\right). \tag{1.16}$$

The profit function can now be expressed as follows:

$$\Pi(L; A, B, \theta, p, w) = p(A - BL)L - wL - \theta \ \ln\left(\frac{p(A - BL)}{w}\right). \tag{1.17}$$

Maximizing with respect to L yields the following first-order conditions for an interior solution:

$$\frac{\partial \Pi}{\partial L} = p(A - 2BL^*) - w + \frac{\theta\ B}{A - BL^*} = 0. \tag{1.18}$$

In Appendix 1.6, it is shown that the equilibrium amount of labor is:

$$L^* = \frac{1}{4pB}\left[(3pA - w) - \sqrt{(3pA - w)^2 - 8p[\theta\ B + A(pA - w)]}\right]. \tag{1.19}$$

Equations (1.17) and (1.18) allow us to study the effect of w on equilibrium profits. The analysis suggests that a reduction in the prevailing wage rate of an economy will have two opposite effects on profit levels: the standard one is to increase profits by reducing the wage bill paid to workers; the other is to reduce profits by indirectly increasing enforcement costs. As shown below, which effect prevails may depend upon the wage level.

Taking the derivative of profits with respect to w at L^*, we have:

$$\frac{\partial \Pi^*}{\partial w} = -L^* + \frac{\theta}{w}. \tag{1.20}$$

Therefore, on the one hand, a marginal reduction in the wage rate pushes up profits by L^* through a reduction in labor costs; on the other hand, profits are brought down by θ/w through larger enforcement costs due to increased incentives to encroach for poorer workers. Note that if $\theta = 0$, so that $\lambda = 1$, thus eliminating the need for enforcement expenditures, we recover Hotelling's lemma by removing the right hand side's second term. With the help of Equation (1.20), the *general* shape of the profit function, Π^*, with respect to the wage rate is derived in Appendix 1.6 and illustrated by Figure 1.2. The curve labelled Π^*_{NE} depicts standard equilibrium profits as a function of w when enforcement costs are nonexistent, i.e. $\theta = 0$.

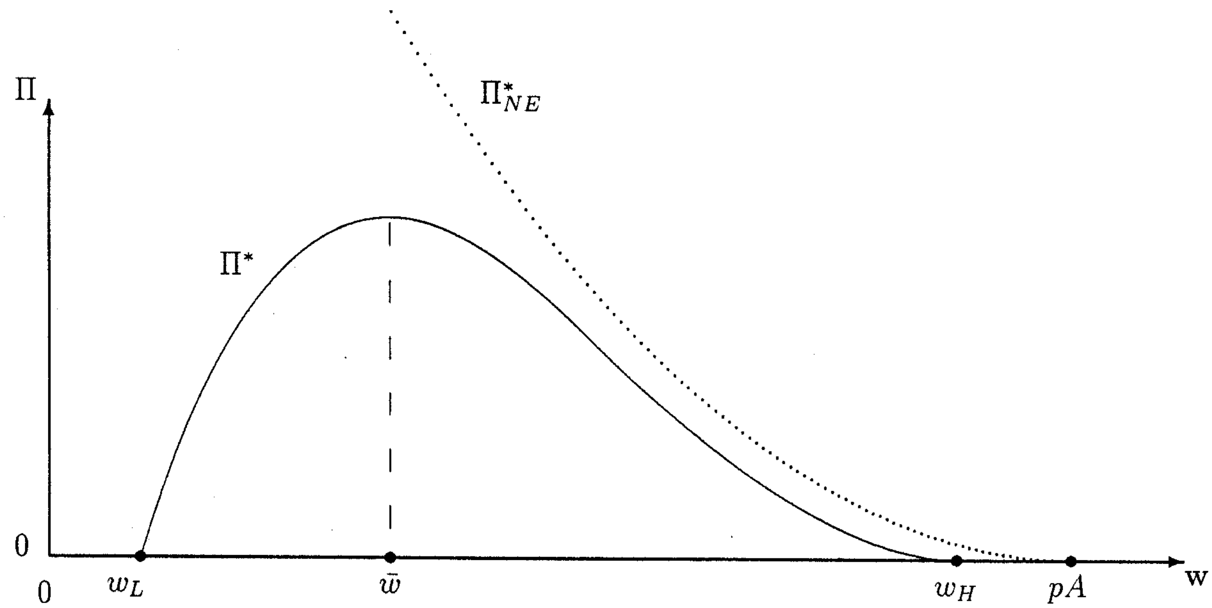

Figure 1.2: Profits as a function of wage

The largest equilibrium rents occur at $\bar{w} = 2\theta B/A$. At $w_H = (1/2)(\ pA + \sqrt{pA(pA - 2\bar{w})}\ )$, we have $\Pi^* = 0$ and $\partial\Pi^*/\partial w = 0$. The wage rate is then so high that gross returns from exploitation are just enough to cover enforcement costs. Further increases in the wage rate make it impossible to cover enforcement costs and all incentives to establish property rights vanish. Notice that $\bar{w} < w_H < pA$. As the wage goes down from w_H, equilibrium profits first behave in the usual way, i.e. they are convex and decreasing with w. At high wages, the direct effect on gross returns from exploitation outweigh the effect on enforcement costs. But as w is further reduced, the function becomes concave. It reaches a slope of zero at $\bar{w}$. At that point, the enforcement effect overtakes the direct exploitation effect and additional reductions in wages reduce profit levels. At wages below w_L, legal incomes are so low that workers' willingness to encroach make enforcement costs prohibitive. The site is left to open access exploitation. It is shown in Appendix 1.6 that w_L is strictly positive[19].

Note that there are discontinuities at w_L and w_H. At wages below w_L and above w_H, negative returns could always be dealt with by employing just enough workers to make the value of average productivity equal to the wage rate. By (1.16), this drives enforcement costs to zero. But profits are also equal to zero. This is essentially equivalent to open access exploitation.

These results regarding the possible behavior of equilibrium profits as the wage rate varies carry interesting implications for the study of property rights determination and natural resource exploitation in less developed countries or in the economic history of industrialized countries. It provides an economic rationale for the lack of well-defined property rights in those economies as compared to industrialized countries. Figure 1.2 suggests that for a less developed country with comparatively low wages, incentives to enclose natural resource properties tend to be weak. For higher wages closer to $\bar{w}$, incentives to enclose properties are more important. It must be stressed that these conclusions do not rest on any exogenous institutional or cultural differences. Given individuals' latent threat to encroach, economic agents may be making the most efficient decision by leaving access to some resources open to all. Any added profit resulting from a reduced level of exploitation would be exceeded by larger enforcement costs at $w \leq w_L$. In this case, distributing titles to hitherto free access natural resource sites as a means of reducing the intensity of exploitation would result in wasted energies as the new owners would find no economic incentives to actually protect the sites from encroachment.

[19]Note that the sign of the second derivative of $\Pi^*(w)$ between 0 and $\bar{w}$ has not been determined. For the present purpose, the important point to make is that within the interval, both the first derivative and w_L are strictly positive.

1.4 The Effects of an Increase in Resource Value on the Delineation of Property Rights

In this section, I propose to verify, within the present context, Demsetz's (1967) conjecture which holds that an increase in the value of a resource is likely to lead, ceteris paribus, to a better delineation of property rights. Demsetz illustrates his point by mentioning a study of the Montagnais Indians in Québec which "established the fact that a close relationship existed, both historically and geographically, between the development of private rights in land and the development of the commercial fur trade." (Demsetz 1967, p. 351). Surmising that the advent of the fur trade resulted in an increase in the value of furs, the study supports his conjecture. Nevertheless, in his *Economic analysis of property rights*, Barzel (1989) points out that Demsetz's conjecture may not always hold. He does recognize that on the one hand, an increase in the value of a resource leads to a higher return from delineation. But on the other hand, incentives for theft are also made higher, thus increasing the costs of policing. There is no a priori reason to believe that the first effect will prevail over the second one. As shown below, the present model indicates that within a partial equilibrium framework, an increase in the value of a resource cannot lead to less well delineated property rights. I present the proof of this assertion here because it provides us with some insight.

Suppose that at some initial price p_0 and wage rate w, an owner maximizes her profits by choosing to employ L_0 workers. Assuming positive profits, this site is operated under private ownership. I will now demonstrate that, ceteris paribus, an increase in the resource price cannot lead to a reduction in equilibrium profits from private ownership; hence, it cannot lead to the abandonment of a site to free access.

Let the price of the resource increase to $p_1 > p_0$, with a constant wage rate. Although it may not be her profit maximizing choice, the owner could then always choose to employ L_1 workers in order to satisfy $VAP_1(L_1) = VAP_0(L_0)$, i.e. such that enforcement costs remain the same. Inserting this into the profit function (1.17), we get the following inequality:

$$[VAP_0(L_0) - w]L_0 - \theta \ \ln\left(\frac{VAP_0(L_0)}{w}\right) < [VAP_1(L_1) - w]L_1 - \theta \ \ln\left(\frac{VAP_1(L_1)}{w}\right), \tag{1.21}$$

since $p_1 R(L_1)/L_1 = p_0 R(L_0)/L_0$ implies $L_1 > L_0$ when $p_1 > p_0$, and $VAP_0 > w$ if initial profits are to be positive. This completes the demonstration that equilibrium profits cannot decrease following an increase in resource price.

The intuition behind the above result is that even though the value of the resource has increased, the owner could always keep enforcement costs the same by reducing the attractiveness of the resource through an adjustment in the average productivity of labor. In effect, it is as if the new price structure allowed the owner to replicate the old one by resorting to some form of "destruction of value".[20] The point is that the initial relative values remain an option at the new higher prices, but the reverse is not true.

[20] I surmise that a similar reasoning would apply to the case presented in Barzel (1989, p. 67). Barzel points out that in a theater with bad and good tickets, it is not possible to say if a doubling in the value of all tickets will lead to a better delineation in prices. He argues that on the one hand, "the difference in valuation between a bad and a good seat would double, too, and therefore the return from pricing the difference would increase... however, the costs of policing would also increase, ... [since] people would gain more from stealing the difference, by buying tickets from the low-priced seats, for instance, and then attempting to occupy the higher priced ones."(Barzel 1989, p. 67). What the present model suggests is that the theater's managers could always replicate the previous price differences either by reducing the relative value of the better seats (making them less comfortable) or by reducing the value of all seats (hiring less famous actors).

1.5 Conclusion

In his seminal paper on property rights, Steven Cheung posed the following question: "Why do exclusive rights not exist for certain actions? Because of the legal institutions, or because policing costs are prohibitive?" (Cheung 1970, p. 58) The role played by the first part of the answer, legal institutions, is now well recognized. The English enclosure movement of the eighteenth century, attributed mostly to a parliamentary statute which substantially reduced the fixed costs associated with enclosure, is a well known case (McCloskey 1975). By contrast, similar attempts at privatizing the commons in Old Regime France met little success due to high litigation costs which are attributed to the lack of support from a central authority (Rosenthal 1992). But in this paper, the set of legal institutions was assumed constant in order to consider the second part of the answer to Cheung's question i.e., the role played by policing costs. To this end, I proposed a framework from which to address the problem of natural resource exploitation when private ownership calls for costly enforcement activities.

Enforcement costs were endogenized by explicitely describing individuals' incentives to encroach on a resource site. It was shown that the equilibrium level of exploitation chosen by the owner exceeds that for which the value of marginal product of labor equals the wage rate. This is so, even though no encroachment occurs in equilibrium. At first sight, it may thus seem that the owner of a site overexploits her resources. However, when the endogenous enforcement costs are accounted for, it becomes clear that this is not the case. The intuition is that an owner has two ways of discouraging encroachers: she can either raise the probability of detection with larger enforcement expenditures, or she can reduce the returns from encroaching by increasing the intensity of exploitation, thus lowering labor's value of average product on the site. In equilibrium, the owner will use a combination of both.

It was also shown that for reasonable functional forms, reductions in the wage rate may actually result in lower equilibrium profits. This is explained by the fact that when the legal wage rate of an economy is already quite low, further reductions so severely foster incentives to encroach that increased enforcement costs outpace any additional direct profit from exploitation. Moreover, there exists a threshold level of the legal wage rate below which positive profits become impossible to achieve, with the result that the site is left to free access. Although these results were obtained with specific functional forms, they did not require unreasonable assumptions about utility, detection, or production functions.

Considering that wages are usually lower in less developed economies, the analysis provides a formalized explanation as to why their property rights on natural resource sites are not so well delineated as in industrialized economies. In some circumstances, the delineation of property rights may be viewed as a response of agents to endogenous economic variables rather than a response to different institutions. In this respect, some policy prescriptions that foster private ownership in less developed countries in order to replicate their industrialized counterparts may end up being more costly than beneficial. Moreover, the distribution of a title to a previously unclaimed resource site may not prevent it from being exploited as a free access resource.

Allowing tenure arrangements to depend on the wage rate brings up the following question: Is a better delineation of property rights a prerequisite to economic growth or is it the other way around? The foregoing analysis suggests that they go hand in hand. Economic growth, when associated with an increase in wages, will reduce the pressure from encroachers and thus lead to a better delineation of property rights. The ensuing gain in efficiency in the exploitation of natural resources should promote growth further. How this works out exactly will require a general equilibrium analysis and goes beyond the scope of this study.

A second line of research which is suggested by the above analysis has to do with the distribution of wealth. It was assumed, all along, that workers' income originated solely from their work wages. There may be a case, here, for a Pareto improvement resulting from a better distribution of property ownership between site owners and workers. By claiming a share of the rents from resource sites, workers' income will increase, thereby reducing enforcement costs for the exploitation of the sites. For the owners, the gains from reductions in enforcement costs may outweigh the foresaken shares of the rents.[21]

Another aspect which has been eschewed is the optimality of private decisions to enclose resource sites and the optimal amount of government support. One would think that the government could make it easier for owners to exclude encroachers, but at what cost? What is the nature of the government's intervention? Is it a substitute or a complement to an owner's enforcement activities?

Finally, the model proposes a framework from which to study the effects of international trade on natural resource exploitation, assuming that tenure arrangements are endogenously determined. The model could be adapted to study the effects of international trade on the environment in a similar framework.

[21]An interesting study which tends to support this beneficial effect resulting from a better distribution of wealth is that of Johnsen (1986). The author argues that the Southern Kwakiutl Amerindians of the Canadian West Coast, whose wealth dependent mostly on salmon, made use of a custom called the Potlatch system as a way to reduce incentives for members of one group to encroach upon another's salmon fishery. The Potlatch consisted of a ceremony where gifts of significant value were exchanged, thus amounting to a redistribution of income. A Potlatch host gained social status proportional to his generosity. As the author notes, the system could only function because salmon being fished in rivers, the territories were relatively easy to protect from encroachment; this was not the case for Amerindians of the interior who dependent mostly on buffalo and antelope, which dwelt over large open areas.

1.6 Appendix

The determination of L^*

In the first part of this appendix, it is shown that L^* is a *local* maximum. It is subsequently shown that L^* is also a *global* maximum.

If we multiply through the first-order condition (1.18) by $A - BL^*$ and rearrange, we get the second degree polynomial:

$$2pB^2L^{*2} - B(3pA - w)L^* + [\theta B + A(pA - w)] = 0. \tag{1.22}$$

Its roots are given by

$$L^*_{1,2} = \frac{1}{4pB}\left[(3pA - w) \pm \sqrt{(3pA - w)^2 - 8p[\theta B + A(pA - w)]}\right], \tag{1.23}$$

where L^*_1 and L^*_2 respectively denote the smallest and largest roots. The condition for a real value of L^* is:

$$(3pA - w)^2 \geq 8p[\theta B + A(pA - w)]. \tag{1.24}$$

Note that the R.H.S. of this inequality must be positive since it is assumed that $w \leq pA$; otherwise positive profits would be impossible to achieve, even in the absence of enforcement costs. Rearranging the inequality, we get: $(pA + w)^2 \geq 8p\theta B$. We will assume throughout that $(pA)^2 > 8p\theta B$, i.e.

$$pA > 8\frac{\theta B}{A}. \tag{1.25}$$

In order for L^*_1 to be a local maximum, it is necessary to show that the second derivative of the profit function is negative at L^*_1. The direct way to do this is to insert the value of L^*_1 into the second derivative of $\Pi(L)$, and verify its sign. But since this leads to a very complex expression, we will proceed indirectly as follows.

We know that $\Pi(L)$ and $\Pi'(L)$ are continuous and finite over the interval $0 \leq L < A/B$. Therefore, since $L^*_{1,2} > 0$ because $\sqrt{(3pA - w)^2 - 8p[\theta\ B + A(pA - w)]} < 3pA - w$, the slope of the profit function changes sign at most twice for $L > 0$. From Equations (1.19) and (1.23), we note that $0 < L^*_1 < (3pA - w)/4pB < L^*_2$. As a result, it suffices to show, for the second derivative to be negative at L^*_1, that $[\partial\Pi/\partial L]_{L=0} > 0$ and $[\partial\Pi/\partial L]_{L=(3pA-w)/4pB} < 0$. The first expression is

$$\left.\frac{\partial\Pi}{\partial L}\right|_{L=0} = pA - w + \frac{\theta B}{A}, \tag{1.26}$$

which is positive since $pA > w$. The second expression is

$$\left.\frac{\partial \Pi}{\partial L}\right|_{L=\frac{3pA-w}{4pB}} = p\left[A - 2B\left(\frac{3pA-w}{4pB}\right)\right] - w + \frac{\theta\, B}{A - B\left(\frac{3pA-w}{4pB}\right)}. \tag{1.27}$$

The R.H.S. will be negative if assumption (1.25) holds. This completes the proof that L^* is a local maximum.

In order to show that L^* is also a *global* maximum, let us proceed with a proof by contradiction.

Suppose that there exists an L' such that $\Pi(L') > \Pi(L_1^*)$. Since $\partial\Pi/\partial L > 0$ for $0 < L < L_1^*$, we must have $L' > L_1^*$.

Choose L_0 such that $VAP(L_0) = w$. We have $\Pi(L_0) = 0$ since both enforcement costs and profits are zero. If $\Pi(L_1^*) > 0$, we must have $L_0 > L_1^*$, since $VAP(L_1^*) > w$ and $\partial VAP/\partial L < 0$.

For $L > L_1^*$, $\Pi'(L)$ can change sign only once at L_2^*. Combining this with the fact that at $\Pi(L_0) = 0$, we have $L_0 > L_1^*$, we get $L' > L_0$. But then $VAP(L') < w$, implying $\Pi(L') < 0 < \Pi(L_1^*)$. A contradiction. This completes the proof that $\Pi(L_1^*)$ is a global maximum.

Equilibrium profits and wage levels

This appendix describes how the curve relating equilibrium profits on a resource site to the prevailing wage rate has been derived. Its construction will proceed in four parts. These four parts provide sufficient information to draw $\Pi^*(w)$ as illustrated in Figure 1.2. Together, parts 1, 2 and 4 explain the portion of curve $\Pi^*(w)$ between $\bar{w}$ and w_H. Parts 1 and 3 explain the portion between 0 and $\bar{w}$. Part 5 is used to show that $\Pi^*(w)$ is continuous and smooth between w_L and w_H.

1. At $\bar{w} = 2\theta B/A$, we have $\partial\Pi^*(\bar{w})/\partial w = 0$, $\Pi^*(\bar{w}) > 0$ and $\partial^2\Pi^*(\bar{w})/\partial w^2 < 0$.
2. There exists w_H, $\bar{w} < w_H < pA$, such that $\Pi^*(w_H) = 0$ and $\partial\Pi^*(w_H)/\partial w = 0$.
3. $\partial\Pi^*/\partial w > 0$ for $w \in (0, \bar{w})$ and $\lim_{w\to 0}\Pi^* = -\infty$. This implies the existence of $w_L \in (0, \bar{w})$ such that $\Pi^*(w_L) = 0$.
4. $\partial\Pi^*/\partial w < 0$ for $w \in (\bar{w}, w_H)$.
5. $\Pi^*(w)$ is continuous and smooth between w_L and w_H.

$$\left.\frac{\partial \Pi^*}{\partial w}\right|_{\bar{w}} = 0$$

Proof: From (1.20), we have $\partial\Pi^*/\partial w = 0 \Leftrightarrow L^* = \theta/w$. Let $w = \bar{w} \equiv 2\theta B/A$ and insert into (1.19) to get $L^* = A/2B = \theta/\bar{w}$. **QED**

$$\left.\frac{\partial^2 \Pi^*}{\partial w^2}\right|_{\bar{w}} < 0$$

Proof: From (1.20), we have

$$\frac{\partial^2 \Pi^*}{\partial w^2} = -\frac{\partial L^*}{\partial w} - \frac{\theta}{w^2}. \tag{1.28}$$

Multiplying Equation (1.18) through by $A - BL^*$, we get the implicit derivative:

$$\frac{\partial L^*}{\partial w} = \frac{A - BL^*}{B(4pBL^*)\left[L^* - \frac{3pA-w}{4pB}\right]}. \tag{1.29}$$

Using the fact that at $\bar{w} = 2\theta B/A$ we have $L^* = A/2B$, we get:

$$\left.\frac{\partial^2 \Pi^*}{\partial w^2}\right|_{\bar{w}} = \frac{L^*}{pA - \bar{w}} - \frac{L^*}{\bar{w}}.$$

Therefore, $\partial^2\Pi^*/\partial w^2 < 0$ at $\bar{w}$ iff $pA > 2\bar{w} = 4\theta B/A$, which we have assumed to hold at (1.25). **QED**

$$\Pi^*(\bar{w}) > 0$$

Proof: Inserting $\bar{w} = 2\theta B/A$ and $L^* = A/2B$ into the profit function (1.17), we get:

$$\Pi^*(\bar{w}) = \frac{pA}{4B/A} - \theta\left[1 + \ln\left(\frac{pA}{4\theta B/A}\right)\right].$$

This implies

$$\Pi^*(\bar{w}) > 0 \Leftrightarrow \frac{pA}{2\bar{w}} > 1 + \ln\left(\frac{pA}{2\bar{w}}\right).$$

This last inequality holds for $pA > 8\theta B/A$. **QED**

$\Pi^*(w_H) = 0, \quad \text{for } w_H \in [\bar{w}, pA)$

Proof: We will show that at w_H, we have $VAP(L_H^*) = w_H$; this implies zero enforcement costs and zero profits.

If $VAP(L_H^*) = w_H$, then $L_H^* = (pA - w_H)/pB$. Substituting into the first-order condition (1.18), we get

$$w_H^2 - pAw_H + pB\theta = 0, \tag{1.30}$$

or equivalently, $w_{H\,1,2} = [pA \pm \sqrt{p^2A^2 - 4pB\theta}]/2$. In order for L_H^* to be a maximum at w_H, Equation (1.19) indicates that we need $L_H^* = (pA - w_H)/pB < (3pA - w_H)/4pB$, or equivalently, $w_H > pA/3$. Since we have assumed that $pA > 8\theta B/A$, this implies

$$\bar{w} < w_H = \frac{pA + \sqrt{(pA)^2 - 4p\theta B}}{2} < pA.$$

L_H^* satisfies the profit maximizing first-order condition at $w_H < pA$ and $VAP(L_H^*) = w_H$. **QED**

$$\frac{\partial \Pi^*(w_H)}{\partial w} = 0$$

Proof: Substitute $L_H^* = (pA - w_H)/pB$ into Equation (1.20) to get $\partial \Pi^*(w_H)/\partial w = -(pA - w_H)/pB + \theta/w_H$. Suppose that $\partial \Pi^*(w_H)/\partial w \neq 0$. Then, from the previous equation, we get $w_H^2 - pAw_H + pB\theta \neq 0$. This contradicts Equation (1.30). **QED**

$$\left.\frac{\partial \Pi^*}{\partial w}\right|_{0<w<\bar{w}} > 0$$

Proof: From Equation (1.20), we have $\partial\Pi^*/\partial w > 0 \Leftrightarrow L^* < \theta/w$. Substituting into Equation (1.19) and rearranging, this implies:

$$\underbrace{w(3pA - w) - 4p\theta B}_{F(w)} < \underbrace{w\sqrt{(3pA - w)^2 - 8p[\theta B + A(pA - w)]}}_{G(w)} \tag{1.31}$$

We need to show that $G(w) > F(w)$ for $w \in (0, \bar{w})$. First, we note that $G(w) > 0$ for $w > 0$. $F(w)$ is a polynomial of degree two with $F'(w) = 3pA - 2w > 0$ for $w < pA$. Its roots are $w_{1,2} = [3pA \pm \sqrt{9(pA)^2 - 16p\theta B}]/2$. Since we have assumed that $pA > 8\theta B/A$, it is easy to show that $w_1 \in (0, \bar{w})$ and $w_2 > w_H$. Since $\bar{w} < pA$, this implies $F(w) \leq 0$ for $w \leq w_1 = [3pA - \sqrt{9(pA)^2 - 16p\theta B}]/2$. Therefore, $F(w) < G(w)$ for $w \leq w_1$.

It remains to show that $F(w) < G(w)$ for $w \in (w_1, \bar{w})$. Within that range, $F(w) \geq 0$, hence $F(w) < G(w) \Rightarrow F^2(w) < G^2(w)$, i.e.

$$G^2(w) - F^2(w) = Aw^3 - (2\theta B + pA^2)w^2 + 3pA\theta Bw - 2p(\theta B)^2 \equiv H(w) > 0. \tag{1.32}$$

Suppose that $H(w) \leq 0$ for some $w \in (w_1, \bar{w})$. Since $H(w_1) > 0$ and $H(\bar{w}) = 0$, this implies that there exists $w^* \in (w_1, \bar{w})$ such that $H(w^*) = 0$. Moreover, since $H(w)$ is a polynomial of degree three, $H'(w)$ has at most two zeros. Therefore, $H(w^*) = H(\bar{w}) = H(w_H) = 0$ where $w^* < \bar{w} < w_H$ implies that $H'(\bar{w}) > 0$. Taking the derivative of $H(w)$, substituting $\bar{w} = 2\theta B/A$ and rearranging, this implies $H'(\bar{w}) = 4(\theta B)^2/A - pA\theta B > 0$, or $pA < 4\theta B/A$. This violates the assumption that $pA > 8\theta B/A$. Therefore, $H(w) > 0$ for $w \in (w_1, \bar{w})$. **QED**

$\lim_{w \to 0} \Pi^*(w) = -\infty$

Proof: Equilibrium profits can be expressed as:

$$\Pi^*(w) = [VAP(L^*) - w]L^* - \theta \ln \frac{VAP(L^*)}{w}, \tag{1.33}$$

where the first term on the R.H.S. of the equality represents direct exploitation profits while the second term represents enforcement costs. From Equation (1.19), we have $\lim_{w\to 0} L^* = [3pA - \sqrt{(pA)^2 - 8p\theta B}]/4pB < A/B$. Therefore, $0 < \lim_{w\to 0} VAP(L^*) < +\infty$. This implies
$\lim_{w\to 0} VAP(L^*)/w = +\infty$. Inserting these results into the the equilibrium profit function, we get finite direct exploitation profits but infinitely large enforcement costs as w approaches zero. **QED**

$$\left.\frac{\partial \Pi^*}{\partial w}\right|_{\bar{w}<w<w_H} < 0$$

Proof: We need to show that $L^* > \theta/w$ for $w \in (\bar{w}, w_H)$. Let us borrow from the expressions defined in Equations (1.31) and (1.32). It was shown that $F(w) > 0$ for $w \in (\bar{w}, w_H)$. Therefore, $H(w) < 0 \Leftrightarrow L^* > \theta/w$ for $w \in (\bar{w}, w_H)$.

Suppose that $H(w) > 0$ for some $w' \in (\bar{w}, w_H)$. Since $H'(w)$ has at most two zeros, and $H(w) > 0$ for $w \in (0, \bar{w})$ and $H'(\bar{w}) < 0$, then $H'(w_H) < 0$. But $H'(w_H) = (A/2)(pA - 4\theta B/A)[pA + \sqrt{(pA)^2 - 4p\theta B}] > 0$ since $pA > 8\theta B/A$ by assumption. A contradiction. Therefore, $H(w) < 0$ for $w \in (\bar{w}, w_H)$. **QED**

Demonstration that $\Pi^*(w)$ is continous and smooth over the interval $(0, w_H]$:

From (1.19), $L^*(w)$ is continous and finite for $w \in (0, w_H]$. This implies that $VAP(L^*(w)) = p(A - BL^*(w))$ is continous and finite over the interval $(0, w_H]$. Hence, $\Pi^*(L^*(w), w)$ is continous over $(0, w_H]$. From (1.29), we have $\partial L^*/\partial w < 0$. Since $\lim_{w \to 0} L^* < A/B$, $\partial \Pi^*/\partial w$, as defined by (1.20), is continous and finite over $(0, w_H]$. This completes the demonstration.

Chapitre 2

Conflicts over Property Rights and Natural-Resource Exploitation at the Frontier

2.1 Introduction

It is a well documented fact that many tropical forest areas are being subject to unsustainable land-use practices which result in severe land degradation and the permanent loss of forest cover. (Repetto, 1988, 1990; Barbier et al., 1991) A crucial feature common to most tropical forest areas consists in the fact that they are located far from the markets and the governments' administrative centers; for this reason, they are often referred to as "frontier regions". The purpose of this study is to try to understand how this particular feature of frontier regions can foster the adoption of unsustainable land-use practices.

There are many factors suspected to contribute to the state of affairs at the frontiers, as there is often a large plethora of agents with various and conflicting interests operating in these regions. In the Brazilian Amazon for instance, Schmink and Wood (1992) list the presence of such diverse types of agents as large ranch and sawmill owners, directors of large mining companies, peasants, wage workers, independent miners, rubber tapers, fishers, Brazil nut collectors, Indians, as well as the many levels of government agencies (federal, state, and local), the military and the police. The authors note the presence of "fundamental contradictions within and between [government] agencies (federal, state, and local)" (p. 15), which testifies that the situation can be a complex one to grasp. There remains, nonetheless, one particularity of frontier settlements which is suspected to have a major impact: it is the presence of tenure insecurity.[1] Indeed, one obvious effect of tenure insecurity is to lower the expected value of long-term gains since the settler may have been evicted from the land before these gains have materialized; hence the reduced incentives to invest in sustainable land-use practices.[2]

The mechanics through which ill-defined property rights may encourage an inefficient exploitation of natural resources have been quite extensively investigated, especially in the case of free-access exploitation.[3] What has not deserved as much attention in the literature, however, is the fact that incompletely defined property rights may result from a deliberate choice by the exploiter of a resource, who must weigh the benefits of better delineated property rights with its costs. Indeed, when the owner of a natural-resource site decides to exploit his site, be it a crop-producing plot of land, a pasture, a fishery, a forest, a hunting ground, or else, he must decide not only on the intensity of exploitation of the resource, but also on the level of expenditures necessary to define and enforce his ownership rights. Now in the case of natural-resource exploitation, the protection of property rights may take different forms: for example, one requires the exclusion of

[1]See, for instance, Schneider (1995), Cruz et al. (1992) and Dorner and Thiesenhuesen (1992).

[2]Another effect of insecure ownership is to limit the availability of credit for investments in productivity-enhancing technologies (Besley, 1995; Feder and Feeny, 1991); this effect will not be considered here.

[3]Classic references are Gordon (1954), Dasgupta and Heal (1979, ch. 3) and Hardin (1968).

encroachers who may try to appropriate some of the output from the site, while another involves an outright contest over who actually owns the site.

When encroachers are costly to exclude, Hotte (1998) has shown that in order to reduce exclusion expenditures, the exploiter may resort to increasing the intensity of exploitation of his resource. The reason is that a more intensive use of the resource lowers the returns from encroachment.

When there is a potential for a contest over a site's ownership, the incumbent may decide to protect his rights of ownership in order to benefit from a long-term, sustained use of the resource. Alternatively, he may decide to "mine" the resource, in which case protection expenditures are reduced by destroying the long-term production potential of the site, in return for the short-term gains of a quick depletion of the resource's stock. It is the choice between those two alternatives that will be considered in this paper.

As mentioned previously, insecure land ownership is particularly prevalent in frontier areas. This situation is explained by the fact that the more remote is the plot of land from the government's administrative centers, the less support the settler will receive in the recognition of his land claims, regardless of their legitimacy.[4] This opens up the possibility of conflicts, as late comers may try to contest the claims of the first settlers in order to evict them and appropriate the land. The present paper develops a model which is intended to capture the fact that the possibility of an eviction may lead the first settler to adopt an unsustainable use of the land. In doing so, the settler's level of expenditures devoted to the delineation of his ownership rights are endogenized, as well as that of the contestant's efforts in attempting to evict the settler. In this respect, competition

[4] Many of the studies referenced in this paper report on this situation. Two good ones are Libecap (1989) and Alston, Libecap and Schneider (1995).

for land is set up as a game between a first settler and a contestant. The analysis proceeds by determining which regime of exploitation and land competition is likely to prevail as the distance from the center varies, taking into account the facts that the government's support in defining property rights wears off with distance, while the value of the output decreases due to higher transport costs.

The proposed model suggests that the introduction of a positive probability of eviction affects the value of the land in quite the same way as an increase in the discount rate. In one possible scenario, the results indicate that near the center, a settler is most likely to decide to protect his rights of ownership and choose a sustainable use of the land; this is because even though low transport costs confer a high value to the land's output and encourage competition for land, the proximity of government agencies which support of the protection of property rights makes it easy for the settler to discourage contestants. As the distance increases, however, he may initially be induced to devote more efforts in protecting his rights of ownership because of the decline in government support. This creates opportunities for conflicts over land and discourages resource conservation. Finally, in more remote areas, competition for land becomes less severe as the output of the land has less value, thus encouraging resource conservation. As will be seen, other scenarios are also possible. The results also indicate that in some cases, a lower discount rate makes it more costly for the settler to protect his rights of ownership. This effect occurs because the lower discount rate contributes to increasing the present value of a sustainable use of the resource. Circumstances under which a lower interest rate may foster the adoption of non-sustainable land-use practices are discussed.

The paper is organized as follows: Section 2 presents a survey of competition for land as it occurs in various parts of the world. In section 3, the distance from the center is fixed in order to derive a settler's value function of the land which takes into account the eventuality of an eviction. The value function of the contestant's activities are similarly derived. In section 4, a game of appropriation between a settler and a contestant is proposed in which the arrival rate of an eviction is endogenized. The reaction functions of both contenders are derived, as well as the precommitment equilibrium for different values of the parameters. One of these parameters being the distance from the center, it is shown how these choices may be affected as the distance from the center varies. In section 5, the choice of a non-sustainable use of the resource is introduced. It is shown how a change in the distance from the center may foster the adoption of non-sustainable land-use practices. A conclusion summarizes the results.

2.2 The Nature of Competition for Land

In order to devise a model of competition for land, it is first necessary to get acquainted with the manner in which it takes place. Since an extensive survey would go beyond the scope of this paper, a collection of selected cases with be presented in turn. Some of the common features between these cases will be summarized thereafter; they will provide a basis for the construction of the model of land competition presented in the following section. Owing to the diversity of the cases considered, it is hoped that the proposed model will be of reasonably general relevance.

The case of the Brazilian Amazon frontier provides a good starting point. The following quote from Bunker (1985) summarizes the situation:

> [...] The enormous distances to administrative centers, the lack of commercial value of the land itself, and the frequent absence of

> the appropriate authorities made the costs of registration far greater than any benefits it might bring. Informal institutions of land tenure based on occupation, use, or sometimes superior force superceded the juridical forms of possession that functioned in the capitalist Brazilian center.
>
> The ranching and lumbering entrepreneurs, attracted by new roads and fiscal incentives, were able to exploit the discrepancies in land tenure institutions. In addition to the presumptive preeminence of national legal forms and titles over locally established use rights in land, these entrepreneurs had greater access to and influence over courts, police, and army detachments. They were further protected by distance from administrative centers to which local occupants might appeal against their violent expulsion. These factors impeded effective state action to control the violence and conflict. [...] (108-9)

In response to a situation that had become chaotic, the Brazilian government created in 1970 the National Institute of Colonization and Agrarian Reform (INCRA) which "was given control over the newly acquired federal lands with the responsibility of classifying land tenure, surveying, selling or colonizing, and titling them. INCRA's assigned goal was to impose an order which would control conflict between various segments of the rural population and regularize the possession and use of land in ways conducive to economic growth..." (109)

As it turned out, opportunities for conflicts over land ownership were not removed by the creation of INCRA, but they did adopt a different form: private interest groups began to devote resources in order to influence INCRA's land allocation policies (110-11).

In their study of the evolution of property rights in the Brazilian Amazon, Alston, Libecap and Schneider (1995) similarly observe that the degree of success of claimants in securing land titles will depend partly on their understanding of the workings of bureaucracies as well as their ability to influence politicians through votes and campaign funds. They add, however, that the farther is a site from the government's administrative center, the lower will be its provision of titling services. Government policy is also important as it will determine "... who receives title (through the allocation formula), when it is assigned (through marking and survey policies, pricing, and other settlement requirements), whether it is secure (through enforcement practices), and whether conflicts are adjudicated (through the police and courts)" (93). As for the settlers, land claiming activities usually took the form of clearing the land's boundaries or building markers around it, notarizing sales receipts, hiring a topographer, and traveling to INCRA offices in attempts to obtain official titles (110). As the authors note, these activities can be regarded as investments by the settlers. They further observe that these investments necessitate considerable efforts and resources from the settlers.

As instances of conflicts, Alston, Libecap and Schneider (1995) also report that in the state of Pará, squatters could claim ownership by invading land that was not being used productively, provided that they have improved it and occupied it for long enough. The initial owner's options were then to accept the invasion, or attempt to evict them or negotiate either a voluntary exodus or a transfer to them.

The above two reports on the nature of land competition on the Brazilian Amazon frontier seems to be quite representative of the manner in which it occurs in many other areas of the world, where property rights to land are not firmly established. The cases presented below attest to this.

In a survey of environmental issues in Mozambique, Dejene and Olivares (1991) suggest that "the land law should recognize the rights of vast numbers of small-holders to the land they cultivate otherwise it will inevitably lead to encroachment by those with economic and political influence" (6). They report that conflicts between subsistence and commercial farmers occur because of the government's lack of knowledge about who actually owns the land. According to them, the government is unable to guarantee tenure security because of insufficient resources devoted to the implementation of a Land Law passed in 1987.

Durham (1979) relates an event that took place during a cotton and cattle boom in the 1950's in Honduras. The owner of a large hacienda built a fence around an area within which small farmers had been establishing homes for years, claiming that it was his. Unable to prove otherwise at the time, the settlers were forcibly removed, those who resisted were jailed, and a government agency sided with the hacienda owner by ordering the eviction of some 50 families. As it was later discovered that the land from which the settlers had been evicted was national, one can see a case where a large landowner devoted resources to influencing government officials, a situation fueled by deficiencies in the land titling records.

In their study of the interactions between land tenure and deforestation, Dorner and Thiesenhusen (1992) are mostly concerned about the fact that in many parts of the world, excessive deforestation in frontier areas often results from tenure insecurity suffered by landowners and settlers. They note that in the 1980's, the threat of a land reform in Paraguay has led to massive deforestation by landowners for fear that their forested areas be declared unproductive. The authors also present the case of the Brazilian Amazon frontier, where small farmers have been driven off their land, often through violent means, by large cattle growers and speculators from the cities. The lack of clear land titles at the frontier, combined with the political influence of large landowners and speculators, has contributed to perpetuating this situation. A similar situation is reported to have taken place in Zaire where, during a process of individualization and titling of land, an élite manipulated the titling mechanism in order to appropriate the land.

Lundahl (1979) reports that around 1950 in Haiti, outsiders began evicting peasants in the lower Artibonite valley after the completion of irrigation works. It was later reported that:

> It was of the opinion that the promise of prosperity created by the important works realized in the Artibonite had aroused an immediate desire to become owners of the lands close to the river among many citizens...
>
> Among the latter there are not only enlightened peasants, but also, and above all, townsmen who have discovered a sudden vocation to become agricultors, and even friends, favorites and members of the previous government acting directly or via intermediaries. (Duvigneaud and Figaro, 1958, p. 1, quoted in Lundahl, 1979, p. 604.)

Lundahl concludes that a peasant's tenure security may be jeopardized by "anything that increases the value of peasant land (604)."

Although this survey of competition is quite limited in scope, it is, in many respects, representative of a large number of cases encountered in the literature. A common thread that binds together all of these cases is the difficulty for the occupier of the land in proving his rights of ownership. Unless the presence of an extensive "legal infrastructure" allows for the *economically* uncontestable registration of land claims at a low cost relative to the value of the land, the claims may not be perfectly secure. As many of the cases presented have reported, frontiers are just such regions characterized by a limited legal infrastructure, a situation which opens up the door for land competition and short-termism in resource conservation.

2.3 The Value of Appropriative Activities

In this section, it is proposed that both the settler's and the contestant's appropriative activities be formulated as investment decisions. The settler invests in delineating his ownership rights, thereby lowering the probability of being evicted. The contestant invests in challenging the settler's claim, thereby increasing the probability of an eviction. As a result, the contenders' investment levels interact to determine the degree of success, hence the value, of their respective projects. But before we consider the strategic implications of the model, let us fix the levels of these appropriative activities; this allows us to derive the values of the contenders' projects for any given pair of investment levels. Strategic equilibria will be computed in the next section. Note also that the analysis applies to a parcel of land which is located at a given distance from the market/administrative center; the effects of varying this distance is relegated to section 2.4.

The model considers the situation of a settler who sets foot on a previously untouched parcel of land in a frontier area. It is assumed that according to the law of the country, being first to arrive provides him with a legitimate right of ownership for the parcel of land, given that he respects some conditions regarding the maximum size of the parcel, the minimum length of stay, the type of use, and so on.[5] The analysis is simplified by assuming that the settler can choose

[5]This is the rule of first possession on which the Homestead Act of 1862 in the United States was based. Similar rules typically apply to tropical frontier regions.

between only two types of resource exploitation: either he opts for an indefinitely-sustainable land use with constant output flow rate y, or he chooses to mine the resource, in which case the productive capital of the land is instantaneously depleted in return for an immediately marketable output stock of size S.[6] The choice between either types of land use is assumed irreversible. In other words, once the land has been cleared and prepared for a sustainable use, its mining is no longer an economically attractive option, and vice versa.

Let $p(d)$ denote the unit output price, net of transport costs, for a plot of land located at distance d from the market/administrative center. Then, in an ideal situation of perfectly- and costlessly-defined property rights, the present value of a sustainable land use, given a private discount rate r, would be $p(d)y/r$. The payoff from land mining is $p(d)S$. Note that the price $p(d)$ is net of the opportunity cost of exploitation and that it is assumed to be the same for both types of land use. The settler would prefer a sustainable use of the land if the following were to hold:

$$\frac{p(d)y}{r} > p(d)S. \tag{2.1}$$

Given that the private and social discount rates are the same,[7] the choice of a sustainable use is socially optimal whenever (2.1) obtains. This will be assumed to be the case throughout the analysis.

When property rights are not perfectly defined, the probability of an eviction will affect the value of the land. Let us see how. For ease of exposition, the first settler is referred to as individual 1 and the contestant as individual 2. Their

[6] A similar choice between two types of land use also appears in Schneider (1995) and Mendelsohn (1994), with the difference that in the case of land mining, they assume that the output flow rate decays at a fixed rate. In practice, of course, the settler may have other options which constitute intermediates from the ones considered here. These two extremes have been chosen in order to simplify the analysis and bring out the effects of tenure insecurity on the choice of the settler.

[7] This is often not the case due to the presence of credit constraints for frontier settlers. See Schneider (1995). This additional constraint will not be considered here.

corresponding levels of investment in appropriative activities are denoted by x_1 and x_2. As mentioned above, these investments affect the probability of the occurrence of an eviction. In order to express this probability in continuous time, an exponential distribution is assumed. Hence, the probability of an eviction having occurred by date t is $Pr\{\tau(x_1, x_2) \leq t\} = 1 - exp\{-f(x_1, x_2)t\}$, where $\tau(x_1, x_2)$ is the date of eviction and $f(x_1, x_2)$ is twice differentiable and is assumed to have the following properties:[8]

$$f = f(x_1, x_2) \geq 0,\ f_1 \leq 0,\ f_2 \geq 0,\ f_{11} \geq 0,\ f_{22} \leq 0,\quad f(x_1, 0)|_{x_1 \geq 0} = 0. \tag{2.2}$$

Higher levels of the settler's investments in tenure security reduce the probability that an eviction will have occurred by date t, while increases in the contestant's investments raise that same probability. Both effects occur at a decreasing rate. The probability of an eviction cannot be negative. In the absence of contesting expenditures, the settler's tenure becomes perfectly secure.

Since the settler receives a flow of income py before being evicted and zero thereafter, his expected payoff from the land can be expressed as a function of his own investment level and that of the contestant as[9] [10]

$$V^1(x_1, x_2) = \int_0^\infty pye^{-rt}e^{-f(x_1,x_2)t}dt - x_1 \tag{2.3}$$

$$= \frac{py}{r + f(x_1, x_2)} - x_1. \tag{2.4}$$

[8]Subscripts refer to partial derivatives with respect to the corresponding arguments of the function.

[9]d has been removed as an argument of p in order to clarify the exposition; it will be reintroduced later.

[10]Note that, in order to concentrate on the issue of tenure insecurity, both contenders are assumed to be neutral towards risk and will thus seek to maximize the present value of their respective "projects".

The effect of introducing a probability of eviction which follows an exponential distribution amounts to increasing the *effective discount rate* of the settler by the value of the exponent.[11]

We now turn to the contestant. In order to evaluate the expected value of his appropriative activities, it is first necessary to determine what will be his tenure situation in the case of a successful eviction, that is, what is the value of the "prize" to be won by the contestant. It will be assumed that once the contestant is successful in evicting the settler, ownership rights over the appropriated plot of land will thereafter be well established. As can be attested by the cases presented in the previous section, such an assumption may be justified by the fact that the activities devoted to challenging the claims of the settler often comprise efforts at influencing public officials or legislation. If a successful eviction is thus backed by an official recognition of the state, one may assume that it becomes significantly more difficult to challenge afterward.[12] As a result, once an eviction occurs, the contestant gains a secured access to an income stream py of infinite duration. He does not, however, enjoy any income flow from the contested parcel of land before an eviction occurs. The expected payoff for the contestant's activities can be expressed as a function of both his own investment level and that of the settler

[11] Mendelsohn (1994) arrives at the same conclusion. The situation is in many respects similar to that of a race for a patent as described in Reinganum (1989, pp. 855-56). Some important differences are that for each contender, the stochastic processes are clearly not independent, and that the players' positions are not symmetrical.

[12] Another plausible assumption would be for the contestant to be in the same situation as the settler once he successfully obtains an eviction. In this case, the prize to be won by the contestant would carry the same value as that of the settler's before the eviction.

as

$$V^2(x_1,x_2) = \int_0^\infty pye^{-rt}(1-e^{-f(x_1,x_2)t})dt \; - \; x_2 \tag{2.5}$$

$$= \frac{py}{r} - \frac{py}{r+f(x_1,x_2)} \; - \; x_2 \tag{2.6}$$

$$= \frac{py}{r} - [V^1(x_1,x_2)+x_1] \; - \; x_2. \tag{2.7}$$

A comparison with expression (2.4) reveals that gross of appropriative activities, the contestant's project may have more value than the settler's if $f(x_1, x_2) > r$; this is so, even though both contenders are assumed to share equal access to credit and intend to make a similar use of the land. Moreover, summing the value of both contender's projects yields

$$V^1 + V^2 = \frac{py}{r} - x_1 - x_2, \tag{2.8}$$

which represents the value of the plot of land when property rights are perfectly and costlessly defined and enforced, minus the expenditures in appropriative activities. Since both contenders will not invest more than the value of their respective projects, this insures that the aggregate amount of resources devoted to appropriative activities will not exceed py/r, the value of the coveted land in the case of perfectly- and costlessly-defined property rights.

Now that we have determined the values of the settler's and the contestant's projects for fixed investment levels x_1 and x_2, it becomes necessary to determine what effort levels will be chosen by these agents. We turn to this by specifying a game between the settler and the contestant.

2.4 A game of appropriation

The problem of a first settler on the frontier is that even though the law may be on his side with respect to the legitimacy of his land claim, the remoteness of the frontier makes it difficult for him to prove it. This is due to the limited presence of a "legal infrastructure" which can assist the settler in proving his claims and creates an opportunity for other individuals to contest the settler's claim and attempt to evict him. The settler, however, can anticipate the arrival of a contestant and engage in tenure-securing expenditures which can take different forms: he may start exploiting the land at a very early date,[13] join a local squatters' association, mark or fence the land, hire the services of a surveyor, plant permanent crops, pay taxes, obtain a notarized title from the nearest town, prepare to defend himself using violent means, etc. Assuming that those tenure-securing expenditures are sunk costs that can be observed by a contestant, the latter responds by choosing a corresponding level of contesting activities. Hence the conflict between a settler and a contestant at the frontier is set-up as a contest in which the settler first chooses the type of land use and the level of tenure-securing expenditures, and then the contestant decides on how much to invest in trying to evict the settler, after having observed the settler's choices.

The timing of the game between the settler and the contestant is as follows: the settler moves first by choosing the type of land use, i.e. whether to mine or sustainably use the land, and, if he opts for a sustainable use, he must decide on a level of tenure-securing expenditures, x_1; he is then followed by the contestant who must choose the level of his expenditures, x_2, devoted to challenge the settler's land claim. The contestant is assumed to be a second mover in the sense that he will be able to observe the settler's choice before he makes his decision. Although this implies a sequence of some sort between each contender's move, the analysis is simplified by assuming that each player's decision is taken at the outset.

[13]See Southey (1978) on rent dissipation due to early arrival of settlers.

In the case of land mining, no conflict occurs since it was assumed that its productive capital was depleted immediately; its payoff is thus pS. In the case of a sustainable use of the land, the settler must decide on how much to invest in tenure security, taking into account the reaction of the contestant. Let us therefore proceed by first deriving the equilibrium value of a sustainable use of the land for the settler. This equilibrium value will subsequently be compared to the value of land mining, in order to determine the conditions under which land mining is preferred by the settler.

Since there are only two players that take part in the conflict, it is convenient to analyze the game by deriving each player's reaction function. This enables us to illustrate the situation with a graph in the (x_1, x_2) space.

From (2.4) and (2.7), the following necessary conditions must hold along the reaction function curves of both the settler and the contestant, respectively,

$$\frac{\partial V^1(x_1,x_2)}{\partial x_1} \leq 0, \quad x_1^* \geq 0, \quad \left[\frac{\partial V^1(x_1,x_2)}{\partial x_1}\right] x_1^* = 0 \tag{2.9}$$

$$-\frac{\partial V^1(x_1,x_2)}{\partial x_2} - 1 \leq 0, \quad x_2^* \geq 0, \quad \left[-\frac{\partial V^1(x_1,x_2)}{\partial x_2} - 1\right] x_2^* = 0. \tag{2.10}$$

where

$$\frac{\partial V^1(x_1,x_2)}{\partial x_1} = \frac{-py}{[r+f(x_1,x_2)]^2} f_1(x_1,x_2) - 1, \tag{2.11}$$

$$\frac{\partial V^1(x_1,x_2)}{\partial x_2} = \frac{py}{[r+f(x_1,x_2)]^2} f_2(x_1,x_2). \tag{2.12}$$

In Appendix 2.7, it is shown that given the assumed properties of the function $f(x_1, x_2)$ in (2.2), the necessary conditions for the contestant are also sufficient for a maximum, and that x_2^* is unique. For the settler, on the other hand, it is shown in Appendix 2.7 that further restrictions on the properties of $f(x_1, x_2)$ are necessary in order to insure that the second-order condition be satisfied. Except for the intuitively appealing properties laid down in (2.2), one cannot tell, a priory, what additional features such a function may have. In what follows, it will be assumed that the settler's second-order conditions are also satisfied.

In the case of interior solutions, the slopes of each contender's reaction function are implicitly derived from (2.9) and (2.10) as, respectively,

$$\frac{dx_1^*}{dx_2} = -\frac{\partial^2 V^1/\partial x_1 \partial x_2}{\partial^2 V^1/\partial^2 x_1}, \qquad (2.13)$$

$$\frac{dx_2^*}{dx_1} = -\frac{-\partial^2 V^1/\partial x_2 \partial x_1}{-\partial^2 V^1/\partial^2 x_2}. \qquad (2.14)$$

By the second-order conditions, both denominators are negative; the sign of the slope will thus be the same as that of the numerator. Note that the contestant's numerator is exactly equal to the negative of the settler's numerator. This implies that in a Nash equilibrium, the slope of each contender's reaction function would be of opposite sign, except for the case where they are both equal to zero.[14] Elaborating on the numerators, we have $\partial^2 V^1/\partial x_1 \partial x_2 = py[2f_1 f_2 - (r+f)f_{12}]/(r+f)^3$. As a result,

$$\frac{dx_1^*}{dx_2} \; \mathbf{S} \; 0 \text{ if and only if } 2f_1 f_2 \; \mathbf{S} \; (r+f)f_{12}. \qquad (2.15)$$

Exactly the reverse conditions hold for the sign of dx_2^*/dx_1.

In order to draw both contender's reaction functions in the (x_1, x_2) space, it is useful to define the curve $G(x_1, x_2) \equiv 2f_1 f_2 - (r+f)f_{12} = 0$, since it is accross that curve that the functions' slopes change sign. Unfortunately, from the properties of $f(x_1, x_2)$ laid out in (2.2), we do not have enough information to draw the curve $G(x_1, x_2) = 0$, nor do we have enough information to determine the signs of the first partial derivatives of $G(x_1, x_2)$ in the general case. For this reason, a specific functional form for $f(x_1, x_2)$ will henceforth be assumed; as argued below, its shape will be motivated by the context.

[14] See Dixit (1987) for similar results in general situations of contests.

First of all, the function must account for the fact that as the distance from the center increases, the state's support in the delineation of the settler's property rights declines monotonically; put differently, the marginal effect of the contestant's activities increase with the distance. Secondly, it must allow for the possibility that there exists a finite level of the setter's investments in tenure security which drives the contestant's activities to zero; this is justified by the fact that in the areas located close to the center, we do not typically observe much conflict over land. Finally, the function must account for the fact that since the first settler *is* the legal claimant to the land, he should be endowed with an initial advantage over the contestant; that is, if both contender's level of appropriative activities are zero, then the settler runs no chance of getting evicted. One simple functional form that conveys those properties is the following one:

$$f(x_1, x_2) = \frac{b(d)x_2}{c + x_1}, \quad \text{with } b(d), c \geq 0 \text{ and } b'(d) > 0, \tag{2.16}$$

where d represents the distance from the center, b is the parameter that determines the marginal effectiveness of the contestant's activities in increasing the probability of an eviction, and c is the parameter that gives an initial advantage to the settler. This function implies that $G(x_1, x_2)\ \mathbf{S}\ 0$ if and only if $f(x_1, x_2)\ \mathbf{T}\ r$. Figure 2.1 illustrates two possible cases for an interior Nash equilibrium (x_1^N, x_2^N), were the two players to move simultaneously: one in which $b(d) < r$ and the other in which $b(d) > r$.

In the case where the settler is a first mover who can precommit to his choice of x_1, we have

$$\frac{dV^1(x_1, x_2)}{dx_1} = \frac{\partial V^1}{\partial x_1} + \frac{\partial V^1}{\partial x_2}\frac{dx_2^*}{dx_1}. \tag{2.17}$$

At any interior Nash equilibrium, we know that $\partial V^1/\partial x_2 < 0$ and $\partial V^1/\partial x_1 = 0$. Moreover, for $b(d) < r$, we have $dx_2^*/dx_1 < 0$, and the reverse for $b(d) > r$.

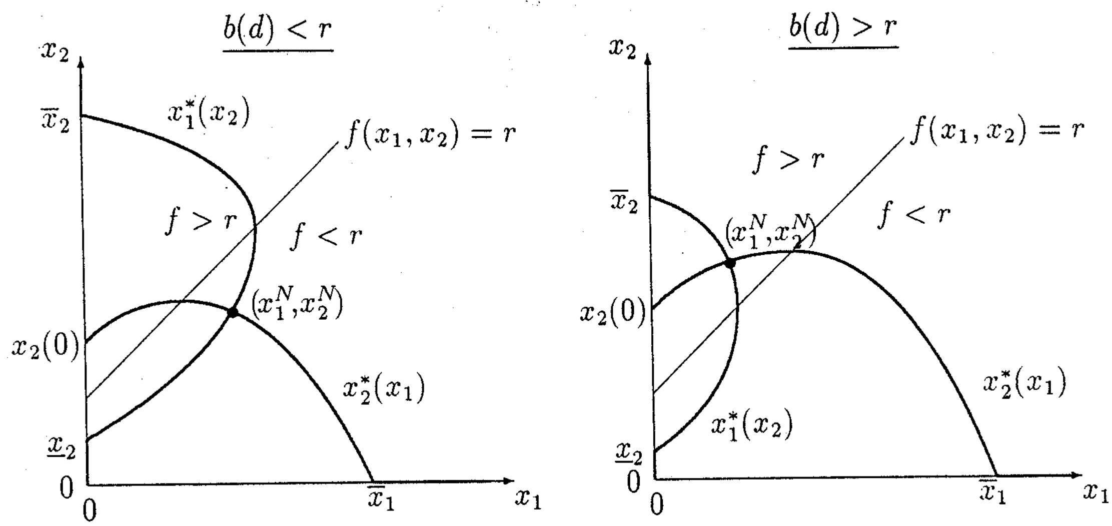

Figure 2.1: Reaction functions for $b(d) < r$ and $b(d) > r$

Denoting the leader-follower equilibrium by the pair (x_1^L, x_2^F), this implies that when $b(d) < r$, the settler will overcommit relative to the Nash equilibrium by choosing $x_1^L > x_1^N$, thereby inducing the contestant to lower his level of activities. Conversely, in the case where $b(d) > r$, the settler will induce a reduction in the contestant's activities by choosing $x_1^L < x_1^N$.

In order to solve for all types of equilibria, the possibility of corner solutions with $x_1^L = 0$ or $x_2^F = 0$ must be considered. This is done in Appendix 2.7 by maximizing $V^1(x_1, x_2)$ with respect to x_1 and x_2 under the constraints given in (2.10) and the non-negativity of x_1. Due to the non-negativity constraints on x_1 and x_2, it is useful to classify the equilibria into four separate regimes. Regime I is defined as the one in which $x_1^L = x_2^F = 0$; regime II as the one in which $x_1^L > 0$ and $x_2^F = 0$; regime III includes the cases with $x_1^L = 0$ and $x_2^F > 0$; and the equilibria with $x_1^L > 0$ and $x_2^F > 0$ define regime IV. Note that regimes I and II include all the equilibria for which no confrontation occurs while no eviction ever takes place. Regime III also denotes a situation without conflict but an eviction will eventually occur. As for regime IV, it includes all the cases with confrontation and eventual eviction.

In the present analysis, we are mostly interested in knowing how the situation evolves as the distance from the center varies. For this reason, Figure 2.2 shows

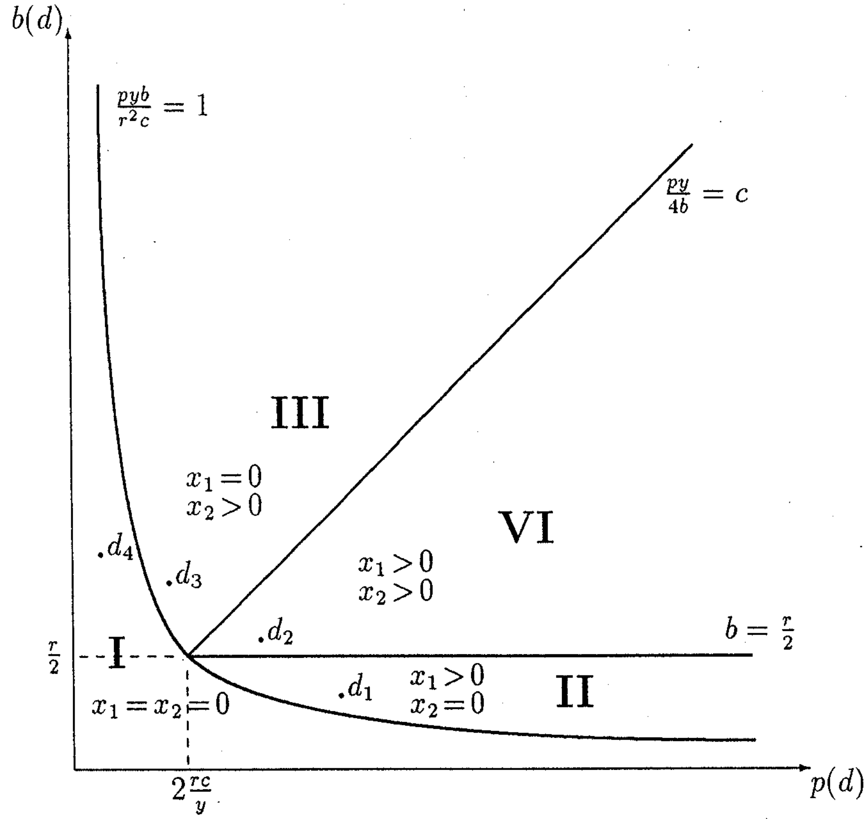

Figure 2.2: Regimes of appropriative activities with sustainable land use

which of the four regime will hold for any combination of the price $p(d)$ and parameter $b(d)$, since it is these two parameters that are assumed to vary with the distance from the center. If the option of a non-sustainable use of the land is left aside for the moment, the graph of Figure 2.2 offers various possible scenarios as the distance from the center increases. Which one will hold in practice will depend on how $p(d)$ and $b(d)$ vary with the distance.

In order to illustrate one possibility, let us consider four plots of land located at distances d_1, d_2, d_3 and d_4, with $d_1 < d_2 < d_3 < d_4$. As explained previously, for $d_i < d_j$, we have $p(d_i) > p(d_j)$ due to transport costs, and $b(d_i) < b(d_j)$ due to the declining effect of the legal infrastructure in support of the settler's ownership claims. At distance d_1, Figure 2.2 depicts the case where a low b, combined with a high price, makes it worthwhile for the settler to invest in completely discouraging a potential contestant from entering into a conflict. As the distance increases to

$d_2 > d_1$, the price decreases while b increases in such a way as to fall into regime IV: even though the price has decreased, the increase in b was so important that it is no more worthwhile for the settler to invest in entirely containing the contestant's efforts. Then, moving farther to d_3, b is now so high in relation to the output price that it becomes too costly for the settler to invest in reducing the contestant's efforts. Finally, at distance d_4, transport costs become so important that the land's output has little value: even though the efforts of the contestant may be quite productive in obtaining an eviction, the advantage that the law confers to the first settler does not make them worthwhile.

The previous illustration represents but one plausible scenario. It is quite possible, for instance, that starting from point d_1, the price decreases so fast as b increases, i.e. $-\Delta p/\Delta d$ is large relative to $\Delta b/\Delta d$, that regimes IV and III are never encountered; in such a case, competition over land never takes place. Moreover, if there exists a plot of land located far enough, say at distance $\overline{d}$, that $p(\overline{d}) = 0$, then, assuming continuity in $p(d)$ and $b(d)$, there will be some plots of land located far enough that warrant no conflict, even though they have positive values. And finally, again assuming continuity in $p(d)$ and $b(d)$, an inspection of Figure 2.2 reveals that if regime IV does occur, it is necessarily preceded by regime II and followed by regime III as one moves away from the center.

We have now determined the regimes that prevail for any combination of $p(d)$ and $b(d)$ in the case of a sustainable use of the land. As far as the settler is concerned, it is now necessary to compare the implied equilibrium value of a sustainable use of the land with that of its alternative use, resource mining.

2.5 Resource Mining

In order for the settler to prefer a sustainable use over land mining, the value of the former must, of course, be larger. For each of the four regimes, it is thus necessary to compute the equilibrium value of a sustainable use of the land in order to compare it with that of land mining. Since the value of land mining is equal to pS, in order for the settler to prefer a sustainable use, the following condition must be satisfied:

$$V(x_1^L, x_2^F) = \frac{py}{r + f(x_1^L, x_2^F)} - x_1^L \;\geq\; pS. \tag{2.18}$$

In regime I, we have $x_1 = 0$ and $f(x_1^L, x_2^F) = 0$. In this case, condition (2.18) is always satisfied and the settler prefers a sustainable use of the land. In regime II, we have $f(x_1^L, x_2^F) = 0$ and $x_1^L = pyb/r^2 - c$, as derived in Appendix 2.7. Inserting into (2.18), we obtain the following condition for a sustainable use of the land:

$$\frac{py}{r} - \left(\frac{pyb}{r^2} - c\right) \;\geq\; pS. \tag{2.19}$$

As for regime III, we have $x_1^L = 0$ and $r + f(x_1^L, x_2^F) = \sqrt{pyb/c}$, such that condition (2.18) can be expressed as follows:

$$\frac{yc}{pb} \;\geq\; S^2. \tag{2.20}$$

And finally, in regime IV, we have $x_1^L = py/4b - c$ and $r + f(x_1^L, x_2^F) = 2b$, which implies the following condition for a sustainable use:

$$\frac{y}{4b} + \frac{c}{p} \;\geq\; S. \tag{2.21}$$

In Figure 2.3, conditions (2.19), (2.20) and (2.21) have been introduced into the graph of Figure 2.2 in the case where $y/r < 2S$. Note that if $y/r \geq 2S$, there is never any mining in regime II.

Figure 2.3 reveals, again, that various scenarios are possible as $p(d)$ decreases and $b(d)$ increases with the distance from the market/administrative center. It can be seen that if $b(d)$ does not increase too sharply as $p(d)$ decreases, resource mining may not take place at all, and the previously considered scenarios may still occur in a similar fashion, as depicted by points d_1 to d_4. If, however, $b(d)$ does increase fast enough, the pair $(p(d_2), b(d_2))$ may fall at point d_2' in Figure 2.3, in which case land mining does take place. One may note that starting from point d_1 in regime II, conflicting situations may be altogether bypassed if, as the distance increases, $b(d)$ increases so fast as to avoid the conditions of region IV, thus making land mining a preferable option for the settler. Such a situation would occur, for instance, when land mining proves to be a relatively attractive option for the settler, such as with a large value of S, the immediately marketable stock of the resource. Whether S is large will depend on the characteristics of the resource.

The role played by the interest rate r warrants a last comment. From the results presented in Appendix 2.7, it can be deduced that as py/r tends toward pS, the upper frontier of regime I merges with the lower frontier of the land mining region. This is not surprising since with $py/r = pS$, any positive tenure-securing expenditure, or any positive probability of eviction, would immediately drive the value of a sustainable use below that of land mining. In this case, therefore, one would never observe any confrontation nor investments in tenure securing expenditures. But as py/r gets larger than pS, as would be the case with a decrease in the interest rate, confrontation equilibria become more likely.

It is often suggested that a reduction in the rate of interest tends to encourage the adoption of sustainable land-use practices in tropical forest areas. Figure 2.4 depicts the effects of decreasing the rate of interest from r_1 to r_2. The graph on

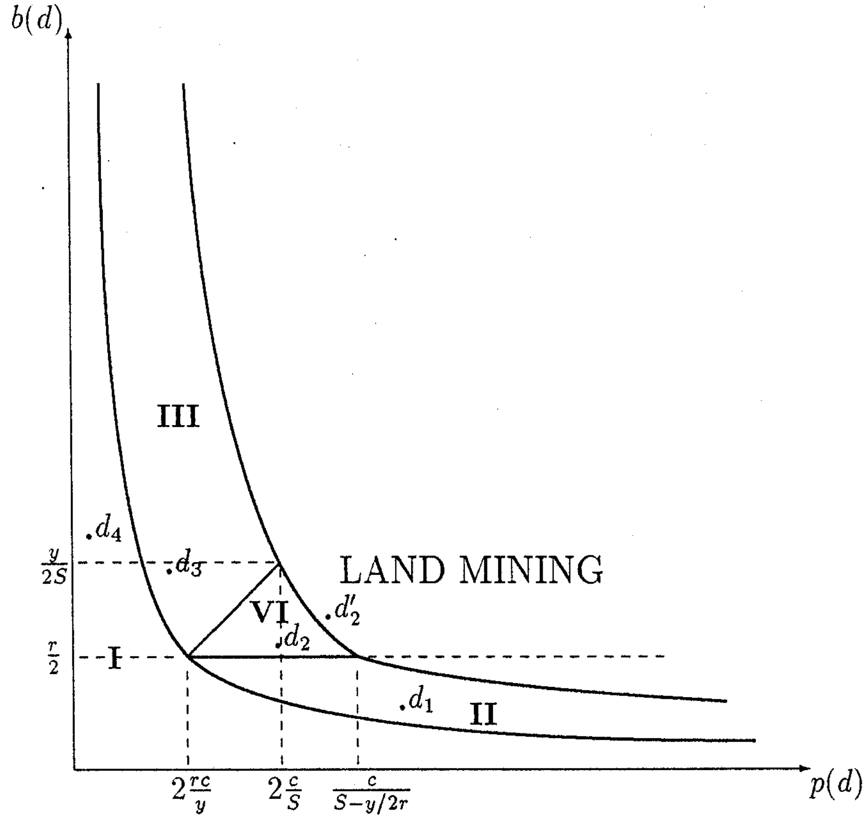

Figure 2.3: Land mining region

the left-hand side illustrates the initial situation with r_1. The graph on the right-hand side depicts the new situation with $r_2 < r_1$ in hard lines, while the dotted lines reproduce the initial limits of the different regimes with r_1. It suggests that if $p(d)$ and $b(d)$ remain constant, a reduction in the rate of interest may increase the likelihood of regimes III and IV occurring to the detriment of regimes I and II. Similarly, land mining is also more likely to occur with the lower discount rate. As an example, figure 2.4 indicates that following the reduction in the interest rate, the regimes pertaining to distances d_1, d_3 and d_4 have not changed; nevertheless, the results of Appendix 2.7 indicate that the level of appropriative activities have increased in all three cases. At distances d_2 and d_5, however, a change of regime has taken place. The plot located at distance d_2 pertained to a regime without conflict and with a sustainable use of the land; at the lower discount rate, it has fallen into the land mining region. As for the plot located at distance d_4, the lower

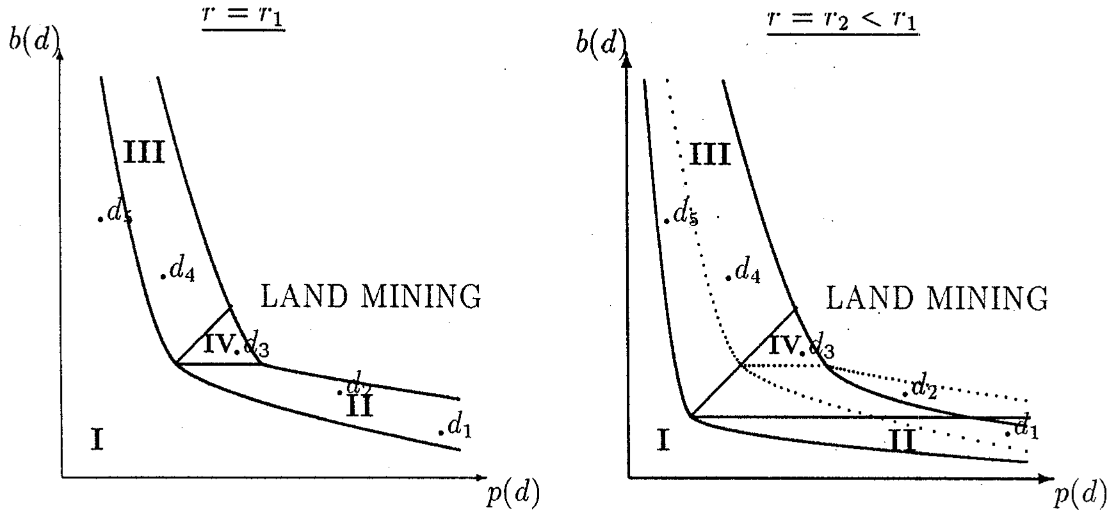

Figure 2.4: Effects of a lower discount rate

interest rate has made it move from a region void of any appropriative activities on either side, to one in which the contestant invests efforts in trying to evict the settler. This suggests that in a world where property rights are costly to define, a reduction in the interest rate may foster the adoption of non-sustainable land-use practices, unless it is accompanied by a stronger presence of the government in support of the settler's tenure-securing efforts.

2.6 Conclusion

This study has proposed a model of competition for land in frontier regions. These regions were characterized by the fact that due to their remote locations, land owners cannot enjoy the strong presence of government agencies in support of their claims to ownership. As a result, contestants may be tempted to try to appropriate the land. The owner of the land, however, may respond by devoting resources in order to better delineate his ownership rights. On the other hand, as the distance to the centers increases, appropriation activities may be discouraged by the fact that transport costs reduce the value of the land's output.

It was seen that as the distance from the center increases, many different scenarios are possible, which depend on how fast the price of the resource decreases with distance in relation to the decreasing presence of government agencies. In one scenario, land owners located near the center protect their rights in such a way as to completely discourage any potential contestant, and the land is used in a sustainable manner. This is due to the strong support of government agencies which are located nearby. A similar equilibrium results at large distances from the center. But in this case, a contestant is not interested in entering into a conflict because transport costs make the value of the output too low to justify appropriative activities. It is at intermediate distances that problems may arise. In one scenario, the land is used in a sustainable way but conflicts take place in which both contenders engage in appropriative activities. In another scenario, no conflict take place but the land is degraded; in this case, land owners have chosen to deplete the stock of the resource as a substitute to the delineation of his property rights.

Comparative statics suggest that a decrease in the discount rate may in some cases encourage land degradation. This is because even though a lower discount rate makes a long term use of the resource more valuable to land owners, it also encourages more competition over land. The second effect may induce some owner to resort to a depletion of the land's productive potential in order to avoid conflict. More generally, this suggests that any policy aimed at increasing the value of land's output in order to promote conservation shoud be combined with a better government support for the delineation of property rights.

2.7 Appendix

Second-order conditions for setter's and contestant's reaction functions

A) Proof that the necessary conditions for the contestant's maximization problem are also sufficient:

It suffices to show that for any given x_1, $V^2(x_1, x_2)$ is concave in x_2. From (2.7) and (2.4), we have

$$\frac{\partial^2 V^2}{\partial x_2^2} = -\frac{\partial^2 V^1}{\partial x_2^2} = \frac{py}{(r+f)^2}\left[f_{22} - \frac{2f_2^2}{r+f}\right] < 0. \tag{2.22}$$

This inequality can be established with the assumption that $f_{22} \leq 0$. Since $V^2(x_1, x_2)$ is strictly concave, the solution to the contestant's maximization problem is also unique.

B) Sufficient conditions for the settler's necessary conditions in (1.13) to be a global maximum for any x_2:

From (1.26), the conditions for $V^1(x_1, x_2)$ to be concave are

$$\begin{aligned}\frac{\partial^2 V^1}{\partial x_1^2} &= \frac{py}{(r+f)^2}\left[\frac{2f_1^2}{r+f} - f_{11}\right], \\ &\leq 0 \text{ iff } \frac{2f_1^2}{r+f} - f_{11} \leq 0.\end{aligned}$$

Making use of the proposed functional form for $f(x_1, x_2)$ in (2.16), we get

$$\frac{\partial^2 V^1}{\partial x_1^2} = \frac{2bx_2}{(c+x_1)^3}\left[\frac{f}{r+f} - 1\right] < 0. \tag{2.23}$$

The second-order conditions are thus verified with the proposed functional form.

The settler's problem with precommitment

The settler is assumed to act as a first mover. If he opts for a sustainable use of the land, he maximizes its value by choosing a level x_1^L of investment in tenure security which takes into account the following reaction of the contestant x_2^F. The reaction of the contestant is defined by the conditions in (1.14). As a result, the settler's program is set-up as follows:

$$\max_{x_1,x_2} V^1(x_1,x_2) \tag{2.24}$$

$$\text{s.t.} \quad \frac{\partial V^2}{\partial x_2} \leq 0, \tag{2.25}$$

$$\frac{\partial V^2}{\partial x_2} x_2 = 0, \tag{2.26}$$

$$x_2 \geq 0, \tag{2.27}$$

$$x_1 \geq 0. \tag{2.28}$$

For this problem, with the Lagrangian function[15]

$$L(x_1,x_2) = V^1(x_1,x_2) - \lambda_1 \frac{\partial V^2}{\partial x_2} + \lambda_2 x_2 + \lambda_3 x_1 + \mu \frac{\partial V^2}{\partial x_2} x_2,$$

the Kuhn-Tucker conditions are

$$L_1 = \frac{\partial V^1}{\partial x_1} + (\mu x_2 - \lambda_1) \frac{\partial^2 V^2}{\partial x_2 \partial x_1} + \lambda_3 = 0, \tag{2.29}$$

$$L_2 = \frac{\partial V^1}{\partial x_2} + (\mu x_2 - \lambda_1) \frac{\partial^2 V^2}{\partial x_2^2} + \mu \frac{\partial V^2}{\partial x_2} + \lambda_2 = 0, \tag{2.30}$$

$$\lambda_1 \geq 0, \quad \lambda_1 \frac{\partial V^2}{\partial x_2} = 0, \tag{2.31}$$

$$\lambda_2 \geq 0, \quad \lambda_2 x_2 = 0, \tag{2.32}$$

$$\lambda_3 \geq 0, \quad \lambda_3 x_1 = 0, \tag{2.33}$$

plus constraints (2.25) to (2.28). Note that it will be useful to make use of the fact that from equation (2.7), we have:

$$\frac{\partial V^1}{\partial x_2} = -\frac{\partial V^2}{\partial x_2} - 1. \tag{2.34}$$

In order for regime I to prevail, the Kuhn-Tucker conditions must be satisfied at $x_1 = x_2 = 0$. Since $f_1(0,0) = 0$, we have $\partial V^1/\partial x_1 = -1$ (see equation (1.26)).

[15]Superscripts ^{L} and ^{F} for the equilibrium values of x_1 and x_2 are removed for clarity of exposition.

The Kuhn-Tucker conditions for regime I become

$$-1-\lambda_1\frac{\partial^2 V^2}{\partial x_2\partial x_1}+\lambda_3=0,$$
$$\frac{\partial V^1}{\partial x_2}-\lambda_1\frac{\partial^2 V^2}{\partial x_2^2}+\mu\frac{\partial V^2}{\partial x_2}+\lambda_2=0,$$
$$\lambda_1\geq 0,\quad \lambda_1\frac{\partial V^2}{\partial x_2}=0,$$
$$\lambda_2\geq 0 \text{ and } \lambda_3\geq 0.$$

If $\lambda_1=0$, we have $\partial V^2(0,0)/\partial x_2\leq 0$, such that $\lambda_3=1$ and $\lambda_2=-\mu\partial V^2/\partial x_2-\partial V^1/\partial x_2>0$. If $\lambda_1>0$, then $\partial V^2(0,0)/\partial x_2=0$. Both cases are consistent with the necessary conditions for regime I. As a result, regime I is defined by the region

$$\left.\frac{\partial V^2}{\partial x_2}\right|_{(0,0)}=\frac{pyb}{r^2c}-1\leq 0. \tag{2.35}$$

In order for regime IV to prevail, the Kuhn-Tucker conditions must be satisfied with $x_1>0$ and $x_2>0$. This implies that $\lambda_3=\lambda_2=\partial V^2/\partial x_2=0$ and the following

$$\frac{\partial V^1}{\partial x_1}+(\mu x_2-\lambda_1)\frac{\partial^2 V^2}{\partial x_2\partial x_1}=0,$$
$$-1+(\mu x_2-\lambda_1)\frac{\partial^2 V^2}{\partial x_2^2}=0.$$

Using the functional form for $f(x_1,x_2)$ proposed (2.16), it is straightforward to show that these two equalities reduce to

$$r+f(x_1^L,x_2^F)=2b, \tag{2.36}$$

where $x_1^L=py/4b-c$ and $x_2^F=(2b-r)py/4b^2$. As a result, regime IV can only prevail if $py/4b>c$ and $b>r/2$.

As for regime II, we have $x_1>0$ and $x_2=0$. This implies that $\lambda_3=0$. If $\lambda_1=0$, we have, from (2.29), $\partial V^1/\partial x_1=0$. This creates a contradiction since at $x_2=0$, we have $\partial V^1/\partial x_1=-1$. If $\lambda_1>0$, we have $\partial V^2/\partial x_2=0$. From (2.29), this implies $\lambda_1=-1/(\partial^2V^2/\partial x_1\partial x_2)>0$ and, from (2.30), $\lambda_2=1-[\partial^2V^2/\partial x_2^2]/[-\partial^2V^2/\partial x_1\partial x_2]$. Making use of functional form in (2.16), λ_2 will be positive iff $b<r/2$. Therefore, regime II prevails when $\partial V^2/\partial x_2|_{(x_1,0)}=0$ and $b<r/2$. From $\partial V^2/\partial x_2|_{(x_1,0)}=0$, we get $x_1=pyb/r^2-c$.

Finally, in regime III, we have $x_1 = 0$ and $x_2 > 0$. This implies that $\lambda_2 = 0$ and $\partial V^2/\partial x_2 = 0$. Inserting this into (2.29) and (2.30) and rearranging, we get $\lambda_3 = -\partial V^1/\partial x_1 - [\partial^2 V^2/\partial x_2^2]/[-\partial^2 V^2/\partial x_1 \partial x_2]$. Making use of functional form in (2.16), it can be shown that λ_3 will be positive iff $c > py/4b$. And from $\partial V^2/\partial x_2 = 0$, we get $x_2 = (c/b)(\sqrt{pyb/c} - r)$.

Chapitre 3

International Trade and Natural-Resource Exploitation with Endogenous Tenure Regimes

3.1 Introduction

Recently, some natural-resource and international-trade economists have been concerned with the effects and desirability of trade when property rights are ill defined in the natural-resource sector (Chichilnisky 1994; and Brander and Taylor 1997, 1998). An interesting and challenging normative proposition from these authors' work resides in the conclusion that there may be *losses from trade* for a country that exports natural resources which are exploited under free access. A common feature of the above mentioned studies consists in the exogenous treatment of the tenure regimes that prevail in the trading regions: industrialized countries exploit their resources under perfectly- and costlessly-defined property rights, whereas these rights are completely absent in their less industrialized trading partners. Tenure regimes are taken as exogenous to these economies. In this respect, the analysis sidesteps a more fundamental issue which may affect the general conclusions and, more to the point, can mitigate the normative effects of trade for a developing country with ill-defined property rights.

In the present analysis, tenure regimes are endogenized through the introduction of an enforcement-cost function. This enforcement-cost function is obtained by describing individuals' incentives to encroach. To this end, the analysis borrows from the formulation proposed in Hotte (1997). In a partial-equilibrium setting, Hotte (1997) shows that when the prevailing wage rate is very low, individuals' incentives to encroach may be so high as to make enforcement costs prohibitively costly for private ownership; natural-resource sites are then left to free-access exploitation.

De Meza and Gould (1992) have studied the effects of private property in a general equilibrium when property rights are costly to enforce. They show that in some cases, when there are private decisions to enforce property rights, there may be inefficient equilibria. Their analysis, however, takes enforcement costs as exogenously given. In the present paper, a general-equilibrium model is proposed in which enforcement costs are endogenously determined, as they depend on individuals' incentives to encroach. It is shown that at low levels of capital endowments, the wage rate may be so low with respect to the resource price that individuals' incentives to encroach make private property prohibitively costly to enforce; a free-access tenure regime prevails in the resource sector. In that case, a move to free trade with higher resource price may induce a shift of tenure regime to private ownership. This is due to the fact that the now higher resource price makes private property profitable. But this is not necessarily welfare improving as the gains from trade may be more than outweighed by expenditures necessary to exclude encroachers.

In the case where the economy is endowed with a more important stock of capital, the higher wage rate, by reducing incentives to encroach, lowers the level of enforcement costs necessary to enclose resource sites; an autarky equilibrium with private property in the resource sector then prevails. But in that case, even though private property prevails both with and without trade, trade is again not necessarily welfare improving. This results from the fact that in order to reduce enforcement costs, owners may resort to hiring more labor than at their marginal cost; they do so in order to reduce the returns from encroachment. As a result, even with private ownership, resources may be exploited below their social cost, thereby creating distortions which make free trade welfare decreasing.

In section 2, a model is developed in which the agents' behavior is described for given factor and good prices. A general-equilibrium framework is introduced in section 3. In the case of autarky, all the prices of the factors of production and the consumption goods are endogenized in the general equilibrium. In the case of free trade, the small open economy assumption is chosen, in which case the price of the resource is fixed at the exogenously given international level. Factors of production are assumed to move freely between the sectors internally, but are immobile internationally. Some implications of the model for the choice of tenure regimes, its effects on welfare and on resource exploitation, are illustrated in section 3.

3.2 The behavior of the agents

The proposed economy is made up of two production sectors: one produces manufactured goods and the other harvests natural resources. The manufacturing sector uses two variable factors: labor L_M and capital K_M. Its total output is aggregated by the Cobb-Douglas function $f(K_M, L_M) = K_M^{\alpha} L_M^{1-\alpha}$, which implies constant returns to scale and decreasing returns to each factor. The resource sector also needs labor as a variable factor, but it must be combined with a resource site in order to harvest natural resources. The economy is endowed with a fixed number $\overline{S}$ of resource sites. As in Brander and Taylor (1997a), I make use of the logistic growth function $G(Z(t)) = aZ(t)(1 - Z(t)/b)$, where $Z(t)$ denotes the stock of some renewable resource on the site at time t, a is the uncongested growth rate, and b is the maximum size of the resource stock. I also assume the Shaefer harvest function $H(t) = \sigma Z(t)L_R$, where, in the present case, L_R represents the total amount of time devoted to the exploitation of a site by all workers and encroachers. In a *steady-state*, the harvest rate is equal to the growth rate of the resource, $H(Z^{ss}) = G(Z^{ss})$, hence $Z^{ss} = b(1 - \alpha L_R/a)$. Inserting this steady-state stock of the resource into the harvest function, we get the steady-state harvest function $H^{ss}(L_R) = \sigma b L_R(1 - \alpha L_R/a)$. This steady-state harvest function being quadratic, the output from *one* resource site will henceforth be represented by the function $R(L_R) = (A - BL_R)L_R$. In order to simplify, the rental rate of the resource stock will be assumed equal to zero in the present analysis. Note that the marginal product of labor can be either positive or negative, allowing for the possibility of a *backward bending* supply curve.[1] Each site can be subject to either free access or private ownership. We will see below that whether a site has been enclosed or not hinges on a cost/benefit analysis of enclosure, as performed by the potential owner of a site. Resource sites are assumed homogeneous and only symmetrical equilibria will be considered here.

There is a total of $\overline{L}$ workers/encroachers, each endowed with one unit of inelastically supplied labor time which is spent in *legitimate* activities. Each worker

[1]The use of a backward bending supply curve for the study of free-access resources has also been analyzed by Gould (1972), De Meza and Gould (1987) and Brander and Taylor (1997b), among others.

can also supply up to one unit of his leisure time in *illegitimate* encroachment activities. Capitalists own all of the economy's physical capital $\overline{K}$ as well as the resource sites.

Individual welfare is represented by the utility function $U(c_R, c_M, h) = [c_R^{\alpha} c_M^{1-\alpha}](1-h)$, where c_R and c_M respectively denote the levels of consumption of the resource and manufactured goods, and $1-h$ measures the amount of leisure available when h units of time are spent encroaching on a resource site. For fixed individual income level I, it is straightforward to show that $c_R = \alpha I/p$ and $c_M = (1-\alpha)I$, where p is the resource price in terms of the manufactured good. Indirect utility levels, given p, I and h, are then $U = (\beta I/p^{\alpha})(1-h)$, where $\beta = \alpha^{\alpha}(1-\alpha)^{1-\alpha}$. Note that the manufactured good will be used as the numéraire throughout the analysis.

We borrow from Hotte (1997) in order to derive individuals' incentives to poach. The sequence of decisions for workers/poachers is as follows: after having (inelastically) supplied one unit of labor time in legitimate activities, workers must decide on how much time h to spend encroaching; this will determine their total income level I; they then choose how to allocate that income between the two consumption goods, c_R and c_M, as determined above. The return from one unit of time spent encroaching is equal to the *value of average product*, VAP, of labor on a resource site. Hence, given a probability λ of being detected while poaching, in which case the value of the gain from poaching is confiscated, a worker's income will be equal to w with probability λ and equal to $w + hVAP$ with probability $1-\lambda$, where w is the prevailing wage rate in the legitimate sector. The problem of individual j thus reduces to choosing the amount of time h_j he spends encroaching. He will choose h_j in order to maximize his expected utility: $E[U_j] = E[(\beta I/p^{\alpha})(1-h_j)] = (\beta/p^{\alpha})\{(1-\lambda)(w+h_j VAP)+\lambda w\}(1-h_j)$.

The value of average product of a worker on a resource site will depend on the amount of workers, L_H, hired by the site's owner, and the total amount of time, $h_j + \sum_{i \neq j} h_i$, that encroachers spend on the site. At the symmetrical equilibrium between encroachers, the first-order condition for an interior solution with a large number N of potential encroachers is (see Hotte 1997):

$$(1-\lambda)VAP(L_H + Nh^*) = w, \tag{3.1}$$

where h^* represents the equilibrium individual amount of time spent encroaching for each of the N encroachers. As N tends to infinity, h^* will tend towards zero (see Hotte 1997). Note that equation (3.1) implies that all else equal, the lower the wage rate, the larger will be the amount of encroachment Nh^*. This is because of the lower opportunity cost of leisure. Furthermore, this equation implies that a site owner may "voluntarily" over-exploit his resource in order to deter encroachers. This is because as the number of hired workers increases, the value of average product of labor decreases on the site, thereby lowering the return from encroachment. In fact, the owner may even resort to hiring labor with negative marginal productivity. Such a case will be illustrated below.

The owner of a site can reduce incentives to encroach by increasing the probability λ of detecting an encroacher. This detection probability will depend on the level of enforcement activities, x, chosen by the owner of the site. In order to reach this level of enforcement activities, the owner needs to hire enforcement labor (guards), L_E, and enforcement capital (fences, guns, cameras, horses, boats, etc), K_E. Hence, $\lambda = \lambda(x)$, with $x = g(K_E, L_E)$. The function $g(K_E, L_E)$ is assumed homogeneous of degree 1. Therefore, cost minimization on enforcement activities implies that the unit cost of x remains constant for given r and w. This unit cost will be denoted by $c(r,w)$. Assuming a constant elasticity of substitution function for enforcement activities, i.e. $g(K_E, L_E) = \gamma[\delta K_E^\rho + (1-\delta)L_E^\rho]^{1/\rho}$, where the elasticity of substitution between labor and capital is equal to $1/(1-\rho)$, cost minimization yields

$$c(r,w) = \frac{1}{\gamma}\left\{\left(\frac{w}{(1-\delta)^{\frac{1}{\rho}}}\right)^{\frac{\rho}{\rho-1}} + \left(\frac{r}{\delta^{\frac{1}{\rho}}}\right)^{\frac{\rho}{\rho-1}}\right\}^{\frac{\rho-1}{\rho}}. \tag{3.2}$$

Since an individual owner takes w and r as given, he will also take the value $c(r,w)$ as given.

Using this cost function, the owner will then choose L_H and x in order to maximize profits, i.e.

$$\max_{x,L_H} \Pi = VAP(L_H + Nh^*)L_H - wL_H - c(r,w)x, \tag{3.3}$$

$$\text{s.t.} \;\; [1-\lambda(x)]VAP(L_H + Nh^*) \leq w. \tag{3.4}$$

Hotte (1997) shows that, in equilibrium, the owner will choose x and L_H such that there is no incentives to encroach, and that (3.4) is satisfied with equality. As a result, $L_R = L_H$ and we obtain the following enforcement-cost function:

$$[1-\lambda(x)]VAP(L_H) = w. \tag{3.5}$$

This relation says that for any level of labor hired to work on a resource site, there corresponds an optimal level of enforcement activities given by

$$x = \lambda^{-1}\left(1 - \frac{w}{VAP(L_H)}\right). \tag{3.6}$$

The problem of the owner of a site can thus be reduced to

$$\max_{L_H} \Pi = VAP(L_H) - wL_H - c(r,w)\lambda^{-1}\left(1 - \frac{w}{VAP(L_H)}\right), \tag{3.7}$$

and thus the sole choice variable becomes the amount of labor L_H to hire.

In order to illustrate, I will assume that the detection probability function takes the form

$$\lambda(x) = 1 - \exp\{-x\}. \tag{3.8}$$

This function says that the probability of detecting an encroacher increases with the level of enforcement activities x, that it does so at a decreasing rate, and that this probability can never be equal to one, i.e. one can never perfectly exclude encroachers. Substitution into 3.5 yields

$$x = \ln\left(\frac{VAP(L_H)}{w}\right). \tag{3.9}$$

Making use of the quadratic production function for a resource site in steady-state, i.e. $R(L_H) = AL_H - BL_H^2$, the first-order condition for an interior solution to the owner's problem becomes

$$\frac{\partial \Pi}{\partial L} = p(A - 2BL_H^*) - w + \frac{c(r,w)B}{A - BL_H^*} = 0, \tag{3.10}$$

where $c(r, w)$ is defined in (3.2). We thus get the following equilibrium amount of labor hired on a privately owned site, as derived in Hotte (1997),

$$L_H^* = \frac{1}{4pB}\left[(3pA - w) - \sqrt{(3pA - w)^2 - 8p[c(r,w)B + A(pA - w)]}\right]. \tag{3.11}$$

Whether we observe private ownership or free access to the resource sites in equilibrium will depend on the levels of the factor prices and the resource price. In a general equilibrium, these values will be endogenously determined.

3.3 The general-equilibrium framework

Conditions for a general equilibrium will now be laid out. With these conditions, the wage rate and the cost of capital become endogenous. In autarky, the resource price is also endogenously determined through the derived demand for the resource and the manufactured goods. In the case of a small open economy with free trade, in which the price of the resource is fixed exogenously by the world price p^T. Although factors will be assumed to move freely between the sectors of our economy, it will be assumed that they cannot move out of the country. As a result, a zero-deficit condition in the balance of payments is imposed.

The case of autarky

Our economy being endowed with a total number of workers $\overline{L}$, a stock of capital $\overline{K}$, and $\overline{S}$ natural-resource sites, the clearing conditions in the labor and capital markets are, respectively,

$$\overline{S}(L_R + L_E) + L_M = \overline{L}, \tag{3.12}$$

$$\overline{S}K_E + K_M = \overline{K}, \tag{3.13}$$

where $L_E = 0$ and $K_E = 0$ in the case of a free-access exploitation.

As noted in the previous section, individual consumption of the manufactured good is equal to a fixed share, $1 - \alpha$, of personal income while that of the resource good is equal to α/p. Since both capitalists and workers are assumed to share the same utility function, aggregate demand for manufactured and resource goods must be respectively given by

$$(1 - \alpha)Y = f(K_M, L_M), \tag{3.14}$$

$$\frac{\alpha}{p}Y = \overline{S}R(L_R), \tag{3.15}$$

where Y denotes the economy's national income.

In the manufacturing sector, property rights are assumed to be costlessly and perfectly delineated. As a result, the profit maximization conditions are

$$f_L(K_M, L_M) = w, \tag{3.16}$$

$$f_K(K_M, L_M) = r, \tag{3.17}$$

where the subscripts denote partial derivatives. The profit maximizing condition in the resource sector was previously derived in (3.10) for the case of a private ownership equilibrium. In the case of a free-access equilibrium, the equilibrium condition is

$$p\frac{R(L_R)}{L_R} = w. \tag{3.18}$$

That is, labor's value of average product is equal to the wage rate, thereby exhausting all rents, as, for instance, in Gordon (1954).

For a level x of enforcement activities, cost minimization with the assumed CES function gives the following demands for enforcement labor and capital:

$$L_E = \left(\frac{w}{1-\delta}\right)^{\frac{1}{\rho-1}} [\gamma c(r,w)]^{\frac{1}{1-\rho}} \frac{x}{\gamma}, \tag{3.19}$$

$$K_E = \left(\frac{r}{\delta}\right)^{\frac{1}{\rho-1}} [\gamma c(r,w)]^{\frac{1}{1-\rho}} \frac{x}{\gamma}, \tag{3.20}$$

in which x satisfies equation (3.9).

National income equals total factor payments plus the rents from the resource sites, i.e.

$$Y = r\overline{K} + w\overline{L} + \overline{S}\Pi, \tag{3.21}$$

where rents Π are zero in the case of a free-access equilibrium and are given by

$$\Pi = pR(L_R) - w(L_R + L_E) - rK_E, \tag{3.22}$$

in the case of private ownership.

With equations (3.12) to (3.22) – equation (3.18) being replaced by equation (3.10) in the case of private ownership – and equation (3.9), we have 12 equations and 11 endogenous variables: L_R, L_M, L_E, K_M, K_E, x, w, r, p, Y and Π. By Walras' law, equation (3.15) is redundant; the system is thus exactly defined.

The case of free trade

In a trade equilibrium, the possibility of some goods being exported and others being imported must be introduced. Let I_M denote imports of the manufactured good and X_R denote exports of natural resources. Equilibrium in the balance of payments requires that

$$I_M = p^T X_R. \tag{3.23}$$

Furthermore, equations (3.14) and (3.15) must be modified in order to account for imports and exports as follows:

$$\begin{aligned} (1-\alpha)Y &= f(K_M, L_M) + I_M, & (3.24)\\ \frac{\alpha}{p^T}Y &= \overline{S}R(L_R) - X_R. & (3.25) \end{aligned}$$

Two endogenous variables have been added, X_R and I_M, along with the balance of payments equation. Assuming a small open economy, the price p^T is now fixed exogenously. The system is thus again exactly defined.

3.4 The effects of trade with endogenous property regimes

The general equilibrium model developed in the previous section allows us to show some possible effects of free trade when tenure regimes are endogenously determined. In particular, we will examine its possible impact on welfare, on equilibrium tenure regimes, and on the level of resource exploitation. As will be seen, the economy's endowment in physical capital plays an important role. The impact of varying its level will thus be explicitly looked at. In order to illustrate the results, the following parameter values will be used:

$$R(L_H) = AL_H - BL_H^2, \text{ with } A = 2 \text{ and } B = 0.05;$$
$$f(K_M, L_M) = K_M^\beta L_M^{1-\beta}, \text{ with } \beta = 0.5;$$
$$U(c_R, c_M, h) = [c_r^\alpha c_M^{1-\alpha}](1-h), \text{ with } \alpha = 0.5;$$
$$g(K_E, L_E) = \gamma[\delta K_E^\rho + (1-\delta)L_E^\rho]^{1/\rho}, \text{ with } \gamma = 0.1, \rho = -1 \text{ and } \delta = 0.5;$$
$$\overline{L} = 12000 \text{ and } \overline{S} = 350.$$

Direct general welfare comparisons are difficult to perform in this model since factor rewards will vary and the economy is composed of both capitalists and workers. As a result, some individuals may win after a transition to free trade and some may loose. In order to perform welfare comparisons, we will make use of an indirect method as proposed in Woodland (1982). Free trade would be welfare increasing if the aggregate consumption vector in autarky is strictly contained within free trade's aggregate budget set. Conversely, we will say that free trade is welfare decreasing if the free-trade aggregate consumption vector is strictly contained within autarky's aggregate budget set, i.e. autarky's national income. The argument, as explained in Woodland (1982), is that lump-sum transfers should be possible in autarky that make everyone better off than with free trade. This method should however be used with caution in the present framework since transfers will change individuals' incomes, thereby influencing workers' incentives to encroach. The resulting variation in enforcement costs should have an impact on production decisions and the production equilibrium will change. Hence the production possibility frontier depends on the distribution of income in this model.[2]

In a first instance, let us fix the economy's physical capital endowment to $\overline{K} = 2800$, and assume that the world price for the resource is $p^T = 0.8$. The

[2]The dependence of the production possibility frontier on the income distribution is a complicated issue that deserves further work, but is beyond the scope of this paper.

results of the simulation are summarized in Table 3.1.[3] An asterisk in the column heading indicates which tenure regime prevails in equilibrium. In autarky, a free-access regime will prevail in equilibrium in the natural-resource sector since positive profits cannot be achieved in the private-ownership equilibrium.[4] This symmetrical free-access equilibrium obtains since as reported in the row "profit per *private* site", positive profits cannot be obtained by enclosing one site. As explained in Hotte (1997), this free-access equilibrium can be attributed to the fact that the wage rate is so low relative to the resource price that individuals' incentives to encroach make enforcement activities prohibitively costly. The equilibrium resource price is $p = 0.488$.

The economy is then allowed to trade freely with the rest of the world, where the resource price is $p^T = 0.8$. Since this resource price is higher than in the autarky equilibrium, it induces the economy to export resources and import manufactured goods. We note, however, that a free access to the resource sites no longer constitutes an equilibrium outcome, since in the case where all sites are subject to a free access, the enclosure of one site provides a positive return of 1.29 to its owner. This move from a free-access regime to a private-property regime is brought about by the increase in the resource price, which has made enclosure profitable. It can also be observed that the intensity of exploitation of the natural-resource sites was reduced from $L_H = 22.86$ in autarky to $L_H = 22.59$ with free trade, even though the price of the resource has increased; this is due to the change of tenure regime. When compared to the neo-classical case of costlessly- and perfectly-delineated property rights, the resource appears to be over-exploited

[3]Simulations were performed using the GAMS software. The program is provided in the Appendix.

[4]Note that the private-ownership equilibrium in autarky is essentially equivalent to the free-access equilibrium since the owners choose to exploit the sites at a level where the average productivity value of labor is equal to the wage rate.

	AUTARKY		FREE TRADE	
	private ownership	free access*	private ownership*	free access
labor per site L_R	22.85	22.85	22.59	26.95
manuf. labor L_M	4000	4000	1615	2568
manuf. capital K_M	2800	2800	925	2800
enfor. labor per site L_E	0	0	7.08	0
enfor. capital per site K_E	0	0	5.36	0
output per site Q_R	19.59	19.59	19.66	17.59
total resource output $\overline{S}Q_R$	6857	6857	6882	6155
manuf. output Q_M	2828	2828	1222	2682
manuf. imports I_M	0	0	2142	1121
resource exports X_R	0	0	2678	1401
aggregate res. cons. C_R	6857	6857	4205	4754
aggregate manuf. cons. C_M	2828	2828	3364	3803
resource price p	0.488	0.488	0.8	0.8
wage rate w	0.418	0.418	0.378	0.522
cost of capital r	0.598	0.598	0.661	0.479
enforcement unit cost $c(r, w)$	10.08	10.08	10.20	10.00
GNP	6693	6693	6728	7606
profit per *private* site Π	0	0	0.96	1.29
enfor. costs per site	0	–	6.22	–

Table 3.1: General equilibria with $\overline{K} = 2800$ and $p^T = 0.8$

in autarky since at $L_H = 22.86$, the marginal product of labor is actually negative. (With $A = 2$ and $B = 0.05$, the marginal product of labor on a resource site will be negative for any $L_H > 20$.) Consequently, one might be led to believe that the free-trade equilibrium is preferable since the amount of labor exploiting the sites has been reduced. This is not necessarily the case. The aggregate consumption levels in the free-trade/private-ownership regime are $C_R = 4205$ and $C_M = 3364$. At the free-access/autarky regime prices, this aggregate consumption basket would cost 5416. Since with a free-access/autarky regime, national income is equal to 6693, this means that the free-trade consumption basket is strictly contained within the aggregate autarky budget set. The main reason for this perverse effect of trade that persists even after resource sites have been enclosed is that in the transition to a private-ownership regime, enforcement expenditures emerge that did not exist in the free-access equilibrium. Although there is a gain in reducing the level of exploitation of the resource, this gain can be more than outweighed by the now positive enforcement expenditures.

Suppose for now that we were to exogenously impose free access to the resource sites after free trade, as proposed by Chichilnisky (1994) and Brander and Taylor (1997a, 1997b, 1998). In that case, because of the increase in resource price, the intensity of exploitation of the resource increases after trade. A computation of the consumption vector reveals that the consumption basket in the free-trade/free-access regime is again strictly contained within the autarky/free-access budget set. This corroborates those authors' findings that there may be losses from trade when resources are exogenously subject to free-access exploitation.

Let us see how the equilibrium changes when our economy's physical capital endowment is increased to $\overline{K} = 4000$, while the world resource price remains at $p^T = 0.8$. We begin by analyzing the effect, in the autarky equilibrium, of increasing the capital endowment. In autarky, free access to the resource sector is no longer an equilibrium outcome. This can be seen in Table 3.2 by observing that when all resource sites are subject to a free-access regime, enclosing one site can yield a positive profit of 0.125. The larger endowment in physical capital has thus induced a movement to enclose resource sites. This occurs because with the larger capital endowment, equilibrium resource price and wage rate have both increased, thereby increasing the profits from enclosed sites. As one would expect, this move to a private-property regime reduces the intensity of exploitation of the resource sites. Considering that in the free-access case, labor on the resource sites has negative marginal productivity, one might think that the enclosure movement constitutes an improvement. Again, this is not necessarily the case. In this economy, the aggregate consumption set in the autarky/private ownership-regime in strictly contained within the aggregate budget set of the free-access/autarky regime.[5] This is a result which is in line with the one obtained by De Meza and Gould (1992), who have shown that in a general equilibrium, when private property is costly to enforce, there may be equilibria where there is more private property than is socially warranted.

As for the move to free trade, an increase in the resource price insures that the private-property outcome still holds. It can be seen that profits from the sites have increased, and so have enforcement costs. But contrary to what one would expect after an increase in price, the intensity of exploitation of the resource sites has diminished. This counter-intuitive outcome deserves interpretation. As men-

[5]Note that the potential loss of welfare that results from enclosing the resource sites is different from that reported in Weitzman (1974) and Cohen and Weitzman (1975). In these two papers, site enclosure increases the overall efficiency of the economy, but the change in factor rewards makes workers worse off. In the present analysis, enforcement costs are such that enclosure of the resource sites may be an inefficient outcome.

	AUTARKY		FREE TRADE	
	private ownership*	free access	private ownership*	free access
labor per site L_R	21.20	22.85	20.91	25.63
manuf. labor L_M	4162	4000	2754	3028
manuf. capital K_M	3612	4000	2255	4000
enfor. labor per site L_E	1.19	0	5.51	0
enfor capital per site K_E	1.11	0	4.99	0
output per site Q_R	19.93	19.59	19.96	18.41
total resource output $\overline{S}Q_R$	6975	6857	6986	6445
manuf. output Q_M	3877	4000	2492	3480
manuf. imports I_M	0	0	1548	838
resource exports X_R	0	0	1935	1048
aggregate res. cons. C_R	6975	6857	5051	5398
aggregate manuf. cons. C_M	3877	4000	4040	4318
resource price p	0.556	0.583	0.8	0.8
wage rate w	0.466	0.500	0.453	0.575
cost of capital r	0.537	0.500	0.553	0.435
enforcement unit cost $c(r, w)$	10.01	10.00	10.03	10.05
GNP	7754	8000	8080	8636
profit per *private* site Π	0.052	0.125	1.26	1.23
enfor. costs per site	1.15	-	5.25	-

Table 3.2: General equilibria with $\overline{K} = 4000$ and $p^T = 0.8$

tioned before, an owner can reduce incentives to encroach through two channels: first, he can directly raise the level of enforcement activities by hiring more enforcement labor and capital; or he can reduce the returns from encroachment by increasing the level of exploitation of the resource, thereby lowering the average productivity of labor – and encroachers – on the site. In a situation where incentives to encroach are high – as is the case with low wages – and the unit cost of enforcement activities is also high, more of the second method will be used. In the present illustration, this is so much so that site owners resort to hiring labor with negative marginal productivity ($L_H > 20$). But when the resource price increases, this second method becomes a relatively more costly means of deterring encroachers. Hence, after a resource price increase, the owner may actually substitute direct enforcement activities for *over-exploitation* of the resource as a means of discouraging encroachers. We thus have a case here where free trade, through an increase in the resource price, entails a reduction in the intensity of exploitation of the resource.

Is the move to free trade welfare improving in this case? Again, free trade's aggregate consumption vector is strictly contained within autarky's aggregate budget set, i.e. $0.556 * 5051 + 4040 < 7754$. This suggests that free trade may still be welfare decreasing, even when a private-property regime holds in equilibrium with and without trade. The potentially welfare decreasing effect of free trade may be explained as follows. The fact that the resource is exploited at a point where the value of labor's marginal productivity is below the wage rate implies that the price of the resource is below its social cost, as would be the case with a free-access regime. Chichilnisky (1994) argues that with free access to natural resources, the comparative advantage in the resource may be more *apparent* than real. But when property rights are costly to enforce, this apparent comparative

	AUTARKY		FREE TRADE	
	private ownership*	free access	private ownership*	free access
labor per site L_R	16.84	22.85	17.16	24.17
manuf. labor L_M	4757	4000	4394	3541
manuf. capital K_M	12788	15000	12318	15000
enfor. labor per site L_E	3.85	0	4.58	0
enfor. capital per site K_E	6.32	0	7.66	0
output per site Q_R	19.50	19.59	19.60	19.13
total resource output $\overline{S}Q_R$	6825	6857	6858	6696
manuf. output Q_M	7800	7746	7357	7288
manuf. imports I_M	0	0	780	708
resource exports X_R	0	0	600	545
aggregate res. cons. C_R	6825	6857	8137	6151
aggregate manuf. cons. C_M	7800	7746	8137	7996
resource price p	1.143	1.130	1.3	1.3
wage rate w	0.820	0.968	0.837	1.029
cost of capital r	0.305	0.258	0.299	0.243
enforcement unit cost $c(r,w)$	10.62	11.13	10.68	11.36
GNP	15599	15492	16273	15993
profit per *private* site Π	3.39	2.47	4.99	3.77
enfor. costs per site	5.09	–	6.12	–

Table 3.3: General equilibria with $\overline{K} = 15000$ and $p^T = 1.3$

advantage may still obtain, even with private ownership. As a result, the increase in national income brought about by a less severe exploitation of the resource and a higher resource price may be more than outweighed by larger enforcement expenditures and the higher resource price faced by consumers.

We now further increase the capital endowment to $\overline{K}$ to 15000 and still assume that the world price, $p^T = 1.3$, is above the autarky price of the resource. The results from the simulation are presented in Table 3.3. Enclosure of the resource sites may now be socially warranted in both autarky and free trade, as the aggregate consumption vectors in both free-access regimes are now strictly contained within the budget sets of the private-ownership regimes. This can be attributed to the fact that a substantial increase in the capital endowment raises the prevailing wage rate so much as to drive down enforcement costs to a level low enough to make private property a desirable outcome. The consumption vector in the free-trade/private-ownership equilibrium is no longer contained within the budget set of the autarky equilibrium. Although this does not necessarily indicate that there are gains from trade, one may presume that with low enough enforcement costs, gains from trade must eventually take hold. This is so because the economy gets closer to the neo-classical case of costlessly- and perfectly- delineated property rights. A larger stock of capital can achieve this, since, by increasing the wage rate, the burden caused by enforcement costs is reduced.

3.5 Conclusion

The object of this paper was to study some possible effects of free trade when tenure regimes in the natural-resource sector are determined endogenously. The costs of enforcing private property were made endogenous by explicitly accounting for individuals' incentives to encroach on a resource site. We have seen that if the decision to encroach by a worker depends on the opportunity cost of his leisure time, incentives to encroach become more important the lower the economy's prevailing wage rate. The decision to enclose, on the other hand, hinges in part on the costs of enforcing private property, which requires the exclusion of encroachers.

Enforcement activities were assumed to require the hiring of labor and physical capital in order to increase the probability of detecting encroachers, thereby lowering incentives to encroach. However, another means of deterring encroachers consists in increasing the intensity of exploitation of the resource. As a result, on a privately owned resource site, labor's marginal product value was seen to be generally lower than the wage rate. If such is the case, the equilibrium social cost of the resource is larger than its price.

A general equilibrium framework was proposed in which the manufacturing sector uses physical capital and labor as production factors. Generally, for a given tenure regime, the higher the economy's endowment in capital, the higher will be the wage rate. As a result, it was shown that an increase in the aggregate stock of capital may lead to a change of tenure regime in the resource sector. This occurs because with a low enough capital endowment, the equilibrium wage rate is so low that incentives to encroach make enforcement prohibitively costly. A free-access tenure regime thus prevails in the resource sector. But as the capital endowment is raised, the higher wage rate eventually makes private property a profitable venture and the resources are exploited under private property. The simulations have shown, however, that this enclosure movement is not necessarily welfare improving. Indeed, the costs of enforcing private property can outweigh the gains from a less severe exploitation of the natural resources.

In a situation where a move to free trade leads to a higher resource price, a case was presented in which the regime of property rights in the resource sector shifts from free access in autarky to private property with trade. This shift is induced by the higher resource price which has made enclosure profitable. Again, as illustrated, this is not necessarily welfare improving. This is so because the added costs of enforcing private property may outweigh the benefits from trade.

Another case was depicted in which trade may still be welfare decreasing, even though a private-property tenure regime prevails both with and without trade. This effect can be explained by noting that even with a private tenure regime, the social cost of the resource may still be above its price. Hence, the comparative advantage over resource production may be more apparent than real, in a fashion similar to that pointed out by Chichilnisky (1994) in the case of free-access tenure regimes. It was observed, however, that even though the price of the resource increases with free trade, it could end up being less severely exploited. This is because with a higher resource price, the owner of a site may prefer to protect his property by employing more enforcement labor and capital, and relying less on over-exploitation of the resource as a means of deterring encroachers.

3.6 Appendix

GAMS program used for simulations

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*gnrlx.gms

*Estimation of general equilibria for free-access and private ownership.
*Due to difficulties encountered in finding the PO equilibrium, its
*equilibrium is found by increasing LR (labour hired on PO site) up to
*the point where its marginal contribution to profits is zero, i.e.
*PI_M = 0.

$OFFSYMLIST OFFSYMXREF
OPTION LIMROW=0,LIMCOL=0,ITERLIM=1000,RESLIM=15000;
OPTION SOLPRINT=On;

FILE RES /gnrl.dat/
FILE CHK /check.dat/

*OPTION NLP=CONOPT;
OPTION NLP=MINOS5;

*  PRODUCTION AND UTILITY FUNCTIONS PARAMETERS:

SCALARS

*  PRODUCTION AND UTILITY FUNCTIONS PARAMETERS:

A       natrl resource production fctn parameter (quadratic) /2/
B       natrl resource production fctn parameter             /0.05/
BETA    manufacture production fctn parameter (cobb-dgls)    /0.5/
ALPHA   utility function parameter (cobb-dgls)               /0.5/
RHO     dctn fctn prmtr (el. of subst. measure (-infty 1))   /-1/
DELTA   detection fctn parameter (share)                     /0.5/
GAMMA   detection fctn parameter (scale parameter)           /0.1/

*  ECONOMY'S ENDOWMENTS

KBAR    total amount of capital in economy          /10000/
LBAR    total amount of labor in economy            /12000/
N       total number of resource sites in economy   /350/

*  ENDOGENOUS VARIABLES EVALUATED AS PARAMETERS

PI      profits on individual resource sites        /1/
LAMBDA  probability of catching trespasser          /0.1/
E       enforcement expenditures on PO site         /1/
PI_P    profits on privatized site                  /1/
LR_P    labor on one privatized site                /1/
```

```
LR_VMP  net value of marg product of labor on res site /1/
THETAX_P
THETA_P

*  PARAMETERS USED FOR PROGRAMMING AND CHECKING PURPOSES

LR_EST  estimated labor                                     /1/
GNP_CHK   factor income equal output value                  /0/
RAD_CHK   radical for LR foc must be positive               /1/
RANGE   range for searching profit max labor on site        /1/
DIFF   difference between val of avrg prod and wage         /1/


CHK_LBPO
CHK_KBPO
CHK_CMPO
CHK_CRPO
CHK_WPO
CHK_RPO
CHK_LEPO
CHK_KEPO
CHK_EPO
GNP_CHKPO
CHK_PIPO
CHK_FOCPO
CHK_CPO

CHK_LBFA
CHK_KBFA
CHK_CMFA
CHK_CRFA
CHK_WFA
CHK_RFA
GNP_CHKFA
CHK_FOCFA


* PARAMETERS FOR STORAGE OF VARIABLE VALUES:

LR_PO
LM_PO
KM_PO
LE_PO
KE_PO
QR_PO
QRTOT_PO
QM_PO
E_PO /1/
P_PO
W_PO
R_PO
GNP_PO
```

```
PI_PO
I_M_PO
THETA_PO

VAL_OE value of consumption at small open economy prices /1/
VAL_FA
P_FA
;

POSITIVE VARIABLES

*  PRODUCTION FACTORS

    LR     labor employed on individual resource site
    LM     total labor employed in manufacturing sector
    LE     enforcement labor hired on individual resource site
    KM     capital hired in manufacturing sector
    KE     enforcement capital hired on individual resource site

*  OUTPUT LEVELS

    QR     resource output per site
    QRTOT  total resource output
    QM     total output of manufactures
    LR_AP  average product of labor on ntrl resource site

*  PRICES

    W      wage rate
    R      cost of capital
    P      resource price
    THETA  enforcement costs multiplier
    THETAX idem

*  VALUES

    GNP    gross national product
;

VARIABLES

    LR_MP    value of marginal product
    BOGUS    bogus maximand
    I_M      imports of manufactures
;

* INITIAL GUESS:

LR.UP = A/B;
LR.LO = 0.01;
LR.L = A/(4*B);
LM.L = LBAR - N*A/(4*B);
```

```
KM.LO = 0.01;
KM.L = KBAR;
LE.UP = LBAR/N;
KE.UP = KBAR/N;
W.L = 1;
W.LO = 0.01;
R.L = 1;
R.LO = 0.01;
P.L = 2.5;
P.LO = 0.01;
P.UP = 10;
LR_AP.L = 3*A/4;
LR_AP.LO = 0.01;
LR_MP.L = A/2;
LM.LO = 0.01;
*THETA.LO = 0.01;
THETAX.LO = 0.01;

EQUATIONS

    QR_EQ          resource site output function
    QRTOT_EQ       total natural resource output
    QM_EQ          manufacturing sector's total output function
    LR_AP_EQ       average productivity of labor on resource site
    LM_EQ          demand for labor in manufacturing
    KM_EQ          demand for capital in manufacturing
    LR_EQ          demand for labor on resource site
    LE_EQ          demand for enforcement labor
    KE_EQ          demand for enforcement capital

    GNP_DEF        definition of gross national product

    THETAX_EQ      parameter to calculate enforcement multiplier
    THETA_EQ       enforcement multiplier

    CLEAR_M        manufacturing goods market clearance
    CLEAR_L        labor market clearance
    CLEARX_L
    CLEAR_K        capital market clearance
    CLEARX_K

    BOGUSEQ        bogus equation for max

    NEOCL_EQ       neo-classical demand for labor on resource site
    FR_ACS_EQ      demand for labor on free-access site
;

QR_EQ..          QR =E= (A - B*LR)*LR;
QRTOT_EQ..       QRTOT =E= N*QR;
QM_EQ..          QM =E= (KM**BETA)*(LM**(1-BETA));
LR_AP_EQ..       LR_AP =E= A - B*LR;
LM_EQ..          W =E= (1-BETA)*((KM/LM)**BETA);
```

```
KM_EQ..          R =E= BETA*((LM/KM)**(1-BETA));
LR_EQ..          LR =E= (1/(4*P*B))*((3*P*A-W) - SQRT(SQR(P*A+W)-8*P*THETA*B));
THETAX_EQ..      THETAX =E= ((1-DELTA)**(1/(1-RHO)))*(W**(RHO/(RHO-1)))
                      + (DELTA**(1/(1-RHO)))*(R**(RHO/(RHO-1)));
THETA_EQ..       THETA =E= (THETAX**((RHO-1)/RHO))/GAMMA;
LE_EQ..          LE =E= ((W/(1-DELTA))**(1/(RHO-1)))
                    *(THETAX**(-1/RHO))*(LOG(P*LR_AP/W))/GAMMA;
KE_EQ..          KE =E= ((R/DELTA)**(1/(RHO-1)))
                    *(THETAX**(-1/RHO))*(LOG(P*LR_AP/W))/GAMMA;

GNP_DEF..        GNP =E= P*QRTOT + QM;

CLEAR_M..        (1-ALPHA)*GNP =E= QM + I_M;
CLEAR_L..        LBAR =E= N*(LR + LE) + LM;
CLEARX_L..       LBAR =E= N*LR + LM;
CLEAR_K..        KBAR =E= KM + N*KE;
CLEARX_K..       KBAR =E= KM;

BOGUSEQ..        BOGUS =E= 1;

NEOCL_EQ..       LR =E= (A - W/P)/(2*B);
FR_ACS_EQ..      W =E= P*(A - B*LR) ;


MODEL NEO_CLASS /QR_EQ, QRTOT_EQ, QM_EQ, LM_EQ, KM_EQ, GNP_DEF,
       CLEAR_M, CLEARX_L, CLEARX_K, NEOCL_EQ, BOGUSEQ/;

MODEL ENFORCE /QR_EQ, QRTOT_EQ, QM_EQ, LM_EQ, LR_AP_EQ, KM_EQ, GNP_DEF,
    CLEAR_M, LE_EQ, KE_EQ, THETAX_EQ,
             THETA_EQ, CLEAR_L, CLEAR_K, LR_EQ, BOGUSEQ/;

MODEL ESTIMATE /QR_EQ, QRTOT_EQ, QM_EQ, LM_EQ, LR_AP_EQ, KM_EQ, GNP_DEF,
    CLEAR_M, LE_EQ, KE_EQ, CLEAR_L, CLEAR_K, BOGUSEQ/;

MODEL FR_ACS /QR_EQ, QRTOT_EQ, QM_EQ, LM_EQ, KM_EQ, GNP_DEF,
       CLEAR_M, CLEARX_L, CLEARX_K, FR_ACS_EQ, BOGUSEQ/;


PUT RES;

SET COUNT  counter /1*500/;
SET COUNT1 /1*1/;
SET COUNT2 /1*1/;
SET COUNT3 /1/;

GAMMA = 0.1;
LOOP(COUNT1,
KBAR = 15000;
LOOP(COUNT2,

PUT RES;
PUT ///"KBAR=", KBAR:8:0, ", LBAR=", LBAR:8:0, ", N=", N:5:0 /
```

```
        "A=", A:5:1, ", B=", B:7:2, " BETA=", BETA:5, ", ALPHA=", ALPHA:5 /
        "GAMMA=", GAMMA:5:2, ", RHO= ", RHO:5:2, " DELTA=" DELTA:5:2 //;
DISPLAY KBAR, GAMMA;

* CLOSED ECONOMY
I_M.FX = 0;
P.UP = 2;
P.LO = 0.01;

$INCLUDE execx.gms

* CALCULATE VALUE OF TOTAL CONSUMPTION OF PO REGIME
* IN CLOSED ECONOMY WITH FA PRICES:
VAL_FA = QRTOT_PO*P.L + QM_PO;
P_FA = P.L;

PUT RES;
PUT "CLOSED ECONOMY:" /;

$INCLUDE display.gms
PUT RES;
PUT //"value of consumption in PO clsd econ with FA prices:", VAL_FA:8:2 /;

LR.UP = A/B;
LR.LO = 0.01;
THETAX.UP = 20;
THETAX.LO = 0.01;
THETA.UP = 20;
THETA.LO = 0.01;
LM.UP = LBAR - N*A/(4*B);
LM.LO = 0.01;
KE.UP = KBAR/N;
KE.LO = 0;
LE.UP = LBAR/N;
LE.LO = 0;

* SMALL OPEN ECONOMY
P.FX =1.3;

I_M.UP = N*(A**2)/(4*B);
I_M.LO = -(KBAR**BETA)*(LBAR**(1-BETA));

$INCLUDE execx.gms

$ONTEXT
* CALCULATE VALUE OF TOTAL CONSUMPTION OF PO REGIME
* IN OPEN ECONOMY WITH FA CLOSED ECONOMY PRICES:
VAL_OE = QRTOT_PO*P_FA + QM_PO;
$OFFTEXT

PUT RES;
```

```
PUT // "SMALL OPEN ECONOMY:" /;

$INCLUDE display.gms

PUT //"value of consumption in PO open econ with FA clsd econ prices:", VAL_OE:8

KBAR = KBAR + 2000;
);

GAMMA = GAMMA + 0.1;
);
```

```
*execx.gms

* PROGRAM EXECUTION FOR PRIVATE OWNERSHIP
* NEO-CLASSICAL EQUILIBRIUM:

NEO_CLASS.OPTFILE = 1;
SOLVE NEO_CLASS USING NLP MAXIMIZING BOGUS;

PI = P.L*QR.L - W.L*LR.L;
GNP_CHK = GNP.L - (W.L*LBAR + R.L*KBAR + PI*N);
DISPLAY PI, GNP_CHK;

*LE.UP = 100;
*KE.UP = 100;



* PROGRAM EXECUTION FOR PRIVATE OWNERSHIP
* WITH COSTLY ENFORCEMENT OF PROPERTY RIGHTS:
* (N.B. USES METHOD OF SEARCH BY INCREASING LR GRADUALLY
* UNTIL EQUILIBRIUM IS REACHED.)

*SET COUNT  counter /1*10/;
RANGE = A/B - LR.L;
LR_EST = LR.L;
THETAX.FX = ((1-DELTA)**(1/(1-RHO)))*(W.L**(RHO/(RHO-1)))
                + (DELTA**(1/(1-RHO)))*(R.L**(RHO/(RHO-1)));
THETA.FX = (THETAX.L**((RHO-1)/RHO))/GAMMA;
* to check for multiple equilibria with PO
*LR_EST = 0;
*RANGE = A/B;

*PUT RES;
*PUT "    ":4, "PI":5, "E":8, "LR_VMP":8, "LR":5 ///;

DIFF = P.L*LR_AP.L - W.L;
E_PO = 1;
LR_VMP = 1;
LOOP(COUNT $ (LR_VMP GE 0 AND E_PO GT 0.01 AND DIFF GT 0),
*LOOP(COUNT,
LR_EST = LR_EST + RANGE/(CARD(COUNT)+1);
LR.FX = LR_EST;

ESTIMATE.OPTFILE = 1;
SOLVE ESTIMATE USING NLP MAXIMIZING BOGUS;

PI_PO = P.L*QR.L - W.L*(LR.L+LE.L) -R.L*KE.L;
E_PO = W.L*LE.L + R.L*KE.L;
DIFF = P.L*LR_AP.L - W.L;
LR_VMP = P.L*(A-2*B*LR.L) - W.L
```

```
                + THETA.L*B/LR_AP.L;
THETA_PO = THETA.L;
DISPLAY PI_PO, E_PO, LR_VMP;
*PUT PI:5:2, E:8:2, LR_VMP:8:4, LR.L:8:2 /;
THETAX.FX = ((1-DELTA)**(1/(1-RHO)))*(W.L**(RHO/(RHO-1)))
                    + (DELTA**(1/(1-RHO)))*(R.L**(RHO/(RHO-1)));
THETA.FX = (THETAX.L**((RHO-1)/RHO))/GAMMA;
);

GNP_CHK = GNP.L - (W.L*LBAR + R.L*KBAR + PI_PO*N);
RAD_CHK = SQR(P.L*A + W.L) - 8*P.L*B*THETA.L;
DISPLAY GNP_CHK, RAD_CHK;


*$ONTEXT
* PROGRAM EXECUTION FOR PRIVATE OWNERSHIP
* WITH COSTLY ENFORCEMENT OF PROPERTY RIGHTS:
* (N.B. USES FOC DIRECTLY)

LR.UP = 1.01*LR.L;
LR.LO = 0.99*LR.L;
THETAX.UP = 1.01*THETAX.L;
THETAX.LO = 0.99*THETAX.L;
THETA.UP = 1.01*THETA.L;
THETA.LO = 0.99*THETA.L;
LM.UP = 1.01*LM.L;
LM.LO = 0.99*LM.L;
KE.UP = 1.05*KE.L;
KE.LO = 0.99*KE.L;
LE.UP = 1.05*LE.L;
LE.LO = 0.99*LE.L;

LOOP(COUNT3 $ (RAD_CHK GT 0 AND E_PO GT 0.01 AND DIFF GT 0),
ENFORCE.OPTFILE = 1;
SOLVE ENFORCE USING NLP MAXIMIZING BOGUS ;

PI_PO = P.L*QR.L - W.L*(LR.L+LE.L) -R.L*KE.L;
E_PO = W.L*LE.L + R.L*KE.L;
THETA_PO = THETA.L;
LR_VMP = P.L*(A-2*B*LR.L) - W.L
                + THETA.L*B/LR_AP.L;
GNP_CHK = GNP.L - (W.L*LBAR + R.L*KBAR + PI_PO*N);
RAD_CHK = SQR(P.L*A + W.L) - 8*P.L*B*THETA.L;
DISPLAY GNP_CHK, RAD_CHK;
DISPLAY PI_PO, E_PO, LR_VMP;
$INCLUDE checkpo.gms
);

PI_PO = P.L*QR.L - W.L*(LR.L+LE.L) -R.L*KE.L;
E_PO = W.L*LE.L + R.L*KE.L;
THETA_PO = THETA.L;
LR_VMP = P.L*(A-2*B*LR.L) - W.L
```

```
                  + THETA.L*B/LR_AP.L;
GNP_CHK = GNP.L - (W.L*LBAR + R.L*KBAR + PI_PO*N);
RAD_CHK = SQR(P.L*A + W.L) - 8*P.L*B*THETA.L;
DISPLAY GNP_CHK, RAD_CHK;
DISPLAY PI_PO, E_PO, LR_VMP;
$INCLUDE checkpo.gms

*$OFFTEXT


LR_PO = LR.L;
LM_PO = LM.L;
KM_PO = KM.L;
QR_PO = QR.L;
QRTOT_PO = QRTOT.L;
QM_PO = QM.L;
P_PO = P.L;
W_PO = W.L;
R_PO = R.L;
GNP_PO = GNP.L;
LE_PO = LE.L;
KE_PO = KE.L;
I_M_PO = I_M.L;



* PROGRAM EXECUTION FOR FREE-ACCESS EQUILIBRIUM:

LR.UP = A/B;
LR.LO = 0.01;
LM.UP = LBAR;
LM.LO = 0.01;
KM.UP = KBAR;
KM.LO= 0.01;


FR_ACS.OPTFILE = 1;
SOLVE FR_ACS USING NLP MAXIMIZING BOGUS;

PI = P.L*QR.L - W.L*LR.L;
GNP_CHK = GNP.L - (W.L*LBAR + R.L*KBAR + PI*N);
DISPLAY PI, GNP_CHK;

* CHECK FOR PROFITABILITY OF PO WHEN ALL IS FREE ACCESS:
THETAX_P = ((1-DELTA)**(1/(1-RHO)))*(W.L**(RHO/(RHO-1))
                    + (DELTA**(1/(1-RHO)))*(R.L**(RHO/(RHO-1)));
THETA_P = (THETAX_P**((RHO-1)/RHO))/GAMMA;
RAD_CHK = SQR(P.L*A + W.L) - 8*P.L*B*THETA_P;
LR_P = (1/(4*P.L*B))*((3*P.L*A-W.L)
           - SQRT(SQR(P.L*A+W.L)-8*P.L*THETA_P*B))$(RAD_CHK GT 0);
PI_P = P.L*(A-B*LR_P)*LR_P - W.L*LR_P
          - THETA_P*LOG(P.L*(A-B*LR_P)/W.L)$(RAD_CHK GT 0);
```

```
DISPLAY PI_P, RAD_CHK;
$INCLUDE checkfa.gms
```

```
*display.gms

PUT //" ":20, "PRIVATE OWNERSHIP"," ":5,"FREE-ACCESS"///;

PUT "labor per site:      ", LR_PO:10:4, LR.L:20:4 /;
PUT "manuf. labor:        ", LM_PO:10:4, LM.L:20:4 /;
PUT "manuf. capital:      ", KM_PO:10:4, KM.L:20:4 /;
PUT "enforcement labor:   ", LE_PO:10:4 /;
PUT "enforcement capital:", KE_PO:10:4 /;
PUT "site output:         ", QR_PO:10:4,  QR.L:20:4 /;
PUT "tot res output:      ", QRTOT_PO:10:4, QRTOT.L:20:4 /;
PUT "manuf output:        ", QM_PO:10:4, QM.L:20:4 /;
PUT "manuf. imports       ", I_M_PO:10:4, I_M.L:20:4 /;
PUT "resource price:      ", P_PO:10:4, P.L:20:4 /;
PUT "wage rate:           ", W_PO:10:4, W.L:20:4 /;
PUT "cost of capital:     ", R_PO:10:4, R.L:20:4 /;
PUT "c(r,w):              ", THETA_PO:10:4, THETA_P:20:4 /;
PUT "GNP:                 ", GNP_PO:10:4, GNP.L:20:4 /;
PUT "profits:             ", PI_PO:10:4 /;
PUT "enfor costs:         ", E_PO:10:4, "0":20 /;
PUT "profits 1 site:      ", " ":10, PI_P:20:4 /;
```

```
*checkpo.gms

*This program checks if all the equilibrium realtions of the model
*are respected.  In the output, the checking variables must be equal
*to zero.


*labor and capital clearing conditions:

CHK_LBPO = LBAR - (N*(LR.L+LE.L) + LM.L);
CHK_KBPO = KBAR - (N*KE.L + KM.L);

*demand for goods:

CHK_CMPO = (1-ALPHA)*GNP.L - (((KM.L**ALPHA)*(LM.L**(1-ALPHA))) + I_M.L);
CHK_CRPO = (ALPHA/P.L)*GNP.L - (N*(A - B*LR.L)*LR.L - (I_M.L/P.L));

*foc in manufacturing sector:

CHK_WPO = (1-BETA)*((KM.L/LM.L)**BETA) - W.L;
CHK_RPO = BETA*((LM.L/KM.L)**(1-BETA)) - R.L;

*enforcement factor demands:

CHK_LEPO = LE.L - ((W.L/(1-DELTA))**(1/(RHO-1)))
           *(THETAX.L**(-1/RHO))*(LOG(P.L*LR_AP.L/W.L))/GAMMA;

CHK_KEPO = KE.L - ((R.L/DELTA)**(1/(RHO-1)))
                 *(THETAX.L**(-1/RHO))*(LOG(P.L*LR_AP.L/W.L))/GAMMA;

*enforcement costs:

CHK_EPO = E_PO - THETA.L*(LOG(P.L*LR_AP.L/W.L));

*national income:

GNP_CHKPO = GNP.L - (W.L*LBAR + R.L*KBAR + PI_PO*N);

*profits on one site:

CHK_PIPO = PI_PO - (P.L*QR.L - W.L*(LR.L + LE.L) - R.L*KE.L);

*foc on one site:

CHK_FOCPO = P.L*(A-2*B*LR.L) - W.L + ((THETA.L*B)/(A-B*LR.L));

*enforcement unit cost:

*CHK_CPO = THETA.L - (1/GAMMA)*((((W.L/((1-RHO)**(1/RHO)))**(RHO/(RHO-1)))
*                 + ((R.L/(RHO**(1/RHO)))**(RHO/(RHO-1))))**((RHO-1)/RHO));
```

```
PUT CHK;

PUT //"CHK_LBPO", CHK_LBPO:10:4, " CHK_KBPO", CHK_KBPO:10:4, " CHK_CMPO",
          CHK_CMPO:10:4, "  CHK_CRPO",  CHK_CRPO:10:4 /;

PUT   " CHK_WPO", CHK_WPO:10:4, " CHK_RPO",  CHK_RPO:10:4 /;

PUT  " GNP_CHKPO", GNP_CHKPO:10:4,
          " CHK_FOCPO",  CHK_FOCPO:10:4, " CHK_LEPO",  CHK_LEPO:10:4,
          " CHK_KEPO",  CHK_KEPO:10:4 /;

PUT   " CHK_EPO",  CHK_EPO:10:4, " CHK_PIPO",  CHK_PIPO:10:4 /;
```

```
*checkfa.gms

*This program checks if all the equilibrium realtions of the model
*are respected.  In the output, the checking variables must be equal
*to zero.



*labor and capital clearing conditions:

CHK_LBFA = LBAR - (N*LR.L + LM.L);
CHK_KBFA = KBAR - KM.L;

*demand for goods:

CHK_CMFA = (1-ALPHA)*GNP.L - (((KM.L**ALPHA)*(LM.L**(1-ALPHA))) + I_M.L);
CHK_CRFA = (ALPHA/P.L)*GNP.L - (N*(A - B*LR.L)*LR.L - (I_M.L/P.L));

*foc in manufacturing sector:

CHK_WFA = (1-BETA)*((KM.L/LM.L)**BETA) - W.L;
CHK_RFA = BETA*((LM.L/KM.L)**(1-BETA)) - R.L;

*national income:

GNP_CHKFA = GNP.L - (W.L*LBAR + R.L*KBAR);

*foc in resource sector:

CHK_FOCFA = W.L - P.L*(QR.L/LR.L);

PUT CHK;

PUT //" CHK_LBFA",  CHK_LBFA:10:4, " CHK_KBFA",  CHK_KBFA:10:4,
      " CHK_CMFA", CHK_CMFA:10:4, " CHK_CRFA",  CHK_CRFA:10:4 /;
PUT   " CHK_WFA", CHK_WFA:10:4,  " CHK_RFA",  CHK_RFA:10:4, "  GNP_CHKFA",
        GNP_CHKFA:10:4, " CHK_FOCFA",  CHK_FOCFA:10:4 /;
```

Synthèse

Dans les deux premiers chapitres de cette étude, nous avons vu que pour le propriétaire d'une ressource, il peut exister un arbitrage à faire entre le niveau d'exploitation de la ressource et les dépenses de protection de la propriété. Cela découle du fait que les incitations à empiéter étaient explicitement prises en compte. Ainsi, plus faible sera l'intensité avec laquelle on exploite une ressource, plus élevée sera la valeur moyenne de son produit et plus les coûts de protection de la propriété seront élevés. L'une des contributions principales de cette étude consiste donc en la proposition que la propriété privée ne résoud pas nécessairement les problèmes de surexploitation des ressources naturelles. En effet, l'exploitant peut soumettre sa ressource à une exploitation très intensive de manière à décourager les activités d'empiètement ou de contestation de la propriété. La ressource sera alors exploitée à un niveau tel que son coût social excédera son prix. Cela peut créer des distorsions dans une économie qui feront en sorte, par exemple, que l'ouverture au libre-échange cause une diminution de bien-être, et ce, même en présence de propriété privée.

Une autre contribution principale de l'étude découle de la démonstration qu'il peut être plus difficile, dans les pays à bas salaires, d'enclore les sites de ressources naturelles. Ceci est dû au fait que les salaires étant plus bas, les individus seraient plus enclins à empiéter car le coût d'opportunité de leur loisir est moins élevé. Ainsi, une explication rationnelle pour la présence plus répandue de sites à accès libre dans les pays en voie de développement fut proposée.

Le résultat précédent fut corroboré, en équilibre général, par le fait que lorsque le stock de capital d'une économie augmente, il se peut fort bien que le régime d'exploitation des ressources naturelles passe de l'accès libre à la propriété privée. Ce résultat découle du fait qu'avec un stock de capital plus élevé, le coût d'opportunité du loisir augmente par le truchement d'une hausse des salaires. Il fut également démontré que l'ouverture au commerce international peut à son tour provoquer un changement de régime de l'accès libre à la propriété privée si le prix de la ressource augmente. Dans ce cas, c'est la hausse du prix de la ressource qui incite à enclore les sites. Bien que ces changements de régimes puissent contribuer à diminuer la pression sur les ressources naturelles, nous avons remarqué que le bien-être des individus peut quand même s'en trouvé diminué. Cela est dû à l'apparition de coûts de protection de la propriété privée.

Une implication majeure de l'étude provient donc de la démonstration que l'exploitation intensive des ressources naturelles peut être utilisée comme substitut aux activités de protection des droits de propriété. Nous avons vu que ce comportement peut avoir un impact particulièrement important dans le cas des problèmes vécus dans les régions frontières. En effet, dans le but de s'éviter les coûts de revendication de la propriété, un exploitant peut préférer le gain de court terme que lui procurera un épuisement rapide du stock productif de la ressource. Dans d'autres cas cependant, il en fera un usage durable, mais alors il pourra se voir disputer sa propriété et un conflit s'ensuivra. Lequel de ces équilibres prévaudra dépendra de certains paramètres exogènes au modèle et de la distance à laquelle le terre se trouve des centres urbains et administratifs.

La modélisation des problèmes vécus dans les régions frontières nous a conduit à la formulation d'une proposition qui peut sembler assez contre-intuitive à première vue. Il s'agit de l'observation qu'une baisse du taux d'actualisation peut encourager la dégradation des ressources naturelles. Ce résultat découle du fait que dans le modèle proposé l'on tienne compte des incitations d'un contestant à se disputer la propriété d'autrui. Dès lors qu'une baisse du taux d'actualisation augmente la valeur d'un usage durable de la ressource, il s'ensuit une hausse des incitations à la contestation. Le propriétaire préférera parfois y répondre en épuisant rapidement le stock productif de la ressource.

Ce travail ouvre plusieurs avenues de recherche future. L'une des plus immédiate découle de ce que les modèles proposés aient gardé sous silence l'implication des gouvernements dans l'appui à la protection de la propriété privée. Tel que l'a remarqué North (1990), l'une des principales raisons d'être d'un gouvernement serait justement de fournir des services de protection, si l'on pense que la production de services de protection est sujette à des économies d'échelle. Les modèles présentés se prêteraient bien à l'étude du niveau optimal d'offre de services de protection gouvernementale. Il serait alors intéressant de voir s'il existe des cas où l'élimination complète des activités d'appropriation est optimale et, inversement, s'il existe des cas où il serait préférable de laisser les gens se disputer la propriété. Dans le cas spécifique de conflits aux frontières, le fait que les gouvernements n'interviennent pas toujours pour résoudre les disputes sur la propriété de la terre suggère qu'il en serait peut-être trop coûteux. Il s'agit, pour s'en convaincre, de penser aux cas du Far-West américain au siècle dernier, ou de l'Amazonie Brésilienne d'aujourd'hui.

Une autre question laissée en suspend concerne la question de la distribution des revenus. Le modèle des chapitres premier et troisième supposait que les travailleurs/empiéteurs n'avaient comme source de revenu que le salaire. Puisqu'une hausse du revenu individuel, par le truchement du coût d'opportunité du loisir, réduit les coûts d'exclusion des empiéteurs, il semblerait qu'une meilleure distribution du revenu des rentes de la terre et du capital puisse résulter en une amélioration parétienne. Si tel est le cas, les capitalistes, dans l'économie étudiée au troisième chapitre, gagneraient peut-être à ce qu'une partie des rentes de leur propriété soit partagée avec les travailleurs. Il en découle une explication rationnelle en faveur d'une redistribution de la propriété de la part des capitalistes. Nous nous retrouverions cependant alors dans une sorte de dilemme du prisonnier, où tous ont intérêt à ce qu'une partie de la propriété soit redistribuée mais individuellement chacun préférerait s'y soustraire. Il faudra l'intervention extérieure d'un gouvernement afin d'en assurer le respect.

Dans le cadre du modèle du troisième chapitre, une redistribution du revenu pourrait également redonner des vertus au commerce international. En effet, contrairement à l'approche qui y était proposée, si on suppose, par exemple, une distribution égalitaire du revenu national entre tous les travailleurs/empiéteurs, les gains à l'échange découlant du commerce international reviendront en entier à ces travailleurs. Ainsi, le libre-échange pourra contribuer à faire diminuer sensiblement les incitations à empiéter, et donc les coûts de protection de la propriété. Il en résulterait alors un gain de bien-être. De manière générale, le fait que la frontière des possibilités de production dépende de la distribution du revenu constitue une avenue de recherche que l'auteur de cette étude entend poursuivre.

Une extension naturelle du modèle du second chapitre consiste en l'introduction d'une dimension temporelle au problème du premier occupant à la frontière. Cela permetterait de prendre en compte le fait qu'avec le temps la frontière se développe de manière à ce que les centres urbains et administratifs se rapprochent. L'efficacité des dépenses de protection de la propriété du premier occupant devrait augmenter graduellement. Il serait intéressant d'analyser comment cela pourrait influencer les choix des adversaires dans la compétition pour la terre et la période optimale d'intervention des autorités.

Une autre piste de recherche est suggérée par le résultat concernant l'effet du niveau de capital sur les régimes d'exploitation d'équilibre. Dans les cas où le niveau du stock de capital physique est élevé, on a vu que le passage du libre-accès à la propriété privée est désirable, mais que ce n'est pas le cas lorsque le niveau de capital est bas. Cependant, on a vu que ce passage pourrait se faire avec de bas niveaux de capital même s'il n'est pas désirable de le faire. Si on introduisait ce cadre d'analyse dans un modèle de croissance, il semblerait donc que si l'on part d'un niveau bas de capital et qu'on l'accumule, il existerait un seuil optimal qui justifierait le passage à la propriété privée. Cependant, si la prérogative de ce passage est laissée aux décisions privées des agents, notre modèle semble suggérer que ce passage surviendra trop tôt. Il s'ensuivrait un ralentissement (blocage?) prématuré de la croissance économique. Il s'agit d'une question que l'auteur de cette thèse espère pouvoir approfondir sous peu.

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