Essays in the Economics of Renewable Resource Management and International Trade

by

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Abstract

The broad objectives of a natural resources management program include economic efficiency, biological sustainability and social equity. While the first is conceptually uncontentious, the last two often pose challenges by bringing in as implicit stakeholders the general public community and the future generations. The 'commons' problem in renewable resource exploitation is often combined in real life with several types of additional externalities, such as cross-sectoral domestic spillover effects in a diversified economy, or transboundary effects due to overexploitation. Moreover, the distributional implications and local scarcity favoured by corrupt resource policies are prone to create social tensions, extensively documented in the literature. The main object of this thesis is the study of some of these effects in closed and open economy settings. The first chapter uses a political economy framework to analyze the link between natural resources and conflict, where an inefficient and corrupt natural resource management is skewed to favour certain groups in society to the detriment of others. The second chapter uses this theory to provide empirical evidence for the importance of resource depletion and corruption as determinants of civil conflicts. The third chapter deals with the transboundary effects posed by open-access exploitation and trade with a mobile resource which disperses between two jurisdictions. The fourth chapter focuses on the interaction between open-access resource harvesting and industrial pollution, as it considers the welfare effects of international trade.

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Dedication

to Bianca and Alex

Introduction

Many renewable resource stocks globally are increasingly reaching their limits. Overexploitation permitted by lax management is compounded by industrial pollution and transboundary issues in the coastal areas of the globe, where about half of the world's population lives. In a study newly released by the United Nations titled 'Stemming Decline of the Coastal Ocean',[1] lack of inter-jurisdictional cooperation, industrial pollution and low domestic governance quality are cited among the prime causes for the continuing lack of success to effectively manage environmental resources around the world: 'For marine environments, the fragmentation across jurisdictions is particularly damaging because neither fish nor pollutants obey political borders and neither should management.'[2] 'Corruption has a long-standing history within environmental management through its effects on the police, political parties, legal/judicial system, and registry and permit services. The result is biased management action, and concomitant failure of stakeholder support.'[3] 'Nursery habitats, for many coastal fishery species, lie inshore in the shallower waters precisely where impacts of coastal development projects are most strong, and the places most subject to pollution from coastal and upland activities.'[4]

The broad objectives of a natural resources management program include economic efficiency, biological sustainability and social equity. While the first is at least conceptually uncontentious, the last two often pose challenges by bringing in as implicit stakeholders the general public community and the future generations. The 'commons' problem in renewable resource exploitation is often combined in real life with several types of additional externalities, such as cross-sectoral domestic spillover effects in a diversified economy, or transboundary effects due to overexploitation. Moreover, the distributional implications and local scarcity favoured by corrupt resource

[1] See Sale et al. (2008).
[2] Idem, p. 3.
[3] Ibid., p. 28.
[4] Ibid., p. 35.

policies and prone to create social tensions are extensively documented in the literature. The main object of this thesis is to study some of these effects in closed and open economy settings. The following paragraphs provide brief descriptions of the four main parts of the thesis.

The first chapter entitled 'Corruption and Conflict in the Management of Environmental Resources' uses a political economy framework to explore the emergence of resource-based civil conflicts driven by group-level discontent. Previous models of resource conflicts are premised on the idea that the desire of enrichment by appropriating resources is the driving force for insurgents. This approach, however, treats the management of the contentious resources as exogenous, while also failing to account for the grassroots dissatisfaction that is often reported to spark and sometimes sustain rebellions. The proposed theoretical model offers a policy-based alternative: under certain conditions related to the quality of governance, discontent about resource management can be instrumental in increasing the likelihood of an insurgency. While influential contributions in the literature tell the 'resource abundance implies opportunity, implies greed-based conflict' story, this paper focuses on relative scarcity to justify discontent and prompt a 'grievance-based' rebellion. The resource policy arises endogenously as a corrupt government trades off industry contributions and the cost posed by manifestations of resource-related discontent. Conservation effects of both *internal pressure*, in the form of civil unrest, and *external pressure* in the form of international trade and aid measures are analyzed in turn, and regulator corruption is shown to be an important ingredient of conflict.

Some of the theoretical hypotheses put forth are explored empirically using a comprehensive panel dataset in the second chapter, titled 'Revisiting the Grievance Hypothesis: An Empirical Analysis of Environmental Depletion and Governance-Based Determinants of Civil Conflict.' This section looks at the effect of environmental depletion and government corruption on the emergence of civil conflicts around the world. In particular, resource depletion, the quality of governance and their interaction are found to be significant and robust determinants of civil conflict incidence.

The third chapter is entitled 'Resource Dispersion and Trading Neighbours: a Spatial Perspective'. The importance of space in analyzing issues pertaining to renewable resources can hardly be overstated. Most renewable resources are spatially heterogeneous with respect to bio-economic variables, such as stock level, growth and mortality rates, carrying capacity of the environment, harvesting costs and effort. This is likely to have important implications both for domestic management regimes and for international policy interactions and externalities. It is shown, in a two-country general-equilibrium framework that acknowledging the spatial dimension via the mobility of the stock has the potential to alter or qualify some of the conservation and welfare results obtained in the canonical models. The previous literature on trade and renewable resources has focused on cases where national resource stocks are independent. Brander and Taylor find that trade leads to resource stock depletion for an open-access resource-exporting country, while the non-resource exporter is necessarily diversified in the two-country framework. In contrast, I find that the country with a comparative advantage in the resource may gain from a conservation point of view, while its partner can specialize in the manufactured good and may incur conservation and even welfare losses from trade. In addition, the paper discusses incentives for unilateral adoption of a resource management program as well as for resource policy coordination between the two countries, in autarky and trade.

The fourth chapter is entitled 'Renewable Resources, Pollution and Trade in a Small Open Economy'. Industrial pollution can have damaging effects on resource-based productive sectors. International trade creates opportunities for overexploitation of the open-access renewable resource but also for separating the sectors spatially. The existing literature suggests that a diversified exporter of the renewable resource good tends to lose from trade due to overdepletion, while the exporter of the non-resource good gains. This paper shows that, depending on the relative damage inflicted by the two industries on the environment, it is possible that the production externality will persist and that specialization in the manufacturing/dirty good may not be the obvious choice from a welfare perspective. Also, the resource exporter does not necessarily have to lose from trade even when specializing incompletely, due to the partially offsetting external effects.

Chapter 1

Corruption and Conflict in the Management of Environmental Resources

1.1 Introduction

Economic policy-making is often responsible for the disenfranchisement of some groups in the society. There is usually more than one interest group vieing for the regulator's favours, and systematically discriminating against one side has the potential to generate conflict. Economic discontent may erupt into violence where the obstacle to a peaceful resolution of disputes is difficult to circumvent. Many economic activities can simply re-locate when the business environment is not satisfactory, so that tensions due to regulation or re-distribution do not accumulate. Natural resources are, however, highly location-specific, and thus grievances are more prone to escalate into open conflicts. There are numerous accounts of the link between natural resources and the prevalence of violence. '[In] many cases, central governments promote unsustainable mining, logging, ranching, and other projects... [which] typically help prop up unrepresentative, sometimes repressive regimes and enrich national elites and foreign corporations, with few benefits accruing to those whose lands are devastated.'[5] Natural resource management decisions, in both the developing and developed countries, are still significantly skewed towards meeting political goals. On the other hand, resource-related violence is an important phenomenon. According to some estimates, more than one in five conflicts worldwide are resource-based,[6] and civil conflicts dwarf inter-state conflicts in terms of casualties, duration and number of participants.[7] Moreover, there is substantial case-study evidence of resource conflicts triggered by an insensitivity to local concerns of

[5] See Renner (1996), p. 59.
[6] See Renner (2002), p. 6.
[7] See Fearon and Laitin (2003), p. 75.

an alliance formed by an opportunistic government and extractive industry interests.[8]

This paper uses a political economy framework to explore how conflict can occur if resource management policies fail to address particular interest group concerns. Although the most common narrative of the origins of civil violence episodes involves some form of group grievances, existing economic models of conflict are instead premised on the idea that the desire of enrichment by resource appropriation is the cause of most rebellions. Moreover, this approach fails to account for the critical support for insurgency of a significant share of the population that is often apparent especially in the initial phases, [9] while the empirical support for this view is not robust. The theoretical model proposed here offers a policy-based alternative: legitimate grievances related to the way in which resources are managed can translate into violence. While the *appropriation* mechanism lacks a clear policy recommendation, the *policy* channel prescribes that devising a more inclusive resource policy has the potential to reduce the incidence of civil conflicts. The focus is first on the government's resource policy, a function of the quality of governance. The resulting environmental outcome may spark legitimate resource-related discontent, regardless of the eventual unfolding of the conflict or shifts in rebels' motivations. Resource depletion may also have regional consequences, for which some form of international intervention might be appropriate. Hence, the model also investigates the effects of international trade measures and of international transfers on such an environment. Specifically, the paper asks whether these 'external pressures', which may complement the 'internal' constraint represented by the possibility of domestic violence against a corrupt government, can be instrumental in curbing depletion, thus indirectly reducing the likelihood of conflict.

There are three agents in this economy: the self-interested government which is responsible for making resource management decisions, the large scale resource extractive industry which can influence policy through regulation - contingent payments, and the small-scale subsistence harvesters

[8] E.g. in Indonesia, the Aceh conflict against the government and ExxonMobil, in Papua New Guinea, the Bougainville conflict against the government and the mining corporation RTZ, in Nigeria, the Niger Delta conflict against Royal Dutch/Shell and other Western oil giants and the government are just some of the largest ones. See Regan in Ballentine and Sherman (eds) (2003), p. 133-166 and Renner (2002), p. 40-47.

[9] Often, declared motives may also proxy for additional underlying causes, while in other instances claims for socio-political justice may mask predatory intentions. E.g. the separatist Papuan Freedom Organization 'did not gain much support from the local population until the 1970s, when it harnessed grievances against a large-scale mining operation.' Renner (2002), p. 43.

who live off the resource and can migrate to take payoff-improving outside opportunities. In a majority of available examples, the basic scenario is similar: wide-scale exploitation of a natural resource benefits large corporations and the financially interested government, while damaging the environment and threatening the way of life of local populations.[10]

The main results of the paper are the following. Absent the shadow of conflict, the opportunistic government attaches a lower effective weight to locals' concerns and sets a larger harvesting quota than optimal, and resource exploitation increases with the corruption of the government and with its myopia, i.e. the rate of time preference parameter. The specter of conflict decreases exploitation in certain environments, where conditions are such that the increased discontent of the locals dominates their induced emigration. While corruption is generally detrimental to stability since it indirectly increases conservationist grievances, more corruption could actually reduce the conflict-generating effect of depletion, a somewhat counter-intuitive finding. Good outside opportunities available for subsistence harvesters fosters migration and has a negative effect, while the level of population has a positive effect on the likelihood of conflict. Provided the parameters are such that the equilibrium level of the resource is not too low, international sanctions targeting the resource management process (in an environment where the government is corrupt and conflict is possible) achieve their conservationist goal whenever they result in producer price reductions, while the effectiveness of conditional international aid can be directly related to government corruption. Thus, the quality of governance plays an important role in assessing the effects of both external (trade or aid) and internal (political violence) pressure.

Most studies on the relationship between resources and conflict - and especially those proposing predatory behaviour as the dominant mechanism for civil conflict - look at easily lootable, high value non-renewables, such as precious minerals. To offer a complementary perspective, the present theoretical model incorporates renewable resources, typically less prone to violent appropriation.[11] Most civil wars occur in developing countries, where

[10] 'In many developing countries, the economic benefits of mining and logging operations accrue to a small business and government elite and to foreign investors. But in case after case, an array of burdens - ranging from expropriation of land, disruption of traditional ways of life, environmental devastation, and social maladies - are shouldered by the local population.' Renner (2002), p. 8.

[11] Renner (2002) notes that when resource *wealth* is the cause of conflict, it is usually associated with lootable minerals, while resource *scarcity* is more often linked with renewables (p. 9.).

large groups depend on the environment for subsistence,[12] and it is broadly agreed that 'most life-giving [natural] resources are renewable'.[13] Alternatively, the model can support the more general interpretation of being concerned with a population's discontent over the general state of the natural environment as managed by a corrupt regime, including deforestation, severe overexploitation of fisheries, soil degradation, water crises, and the two parties competing for the government's favours can be called *harvesters* and *conservationists*.[14]

The economics of conflict is an emerging sub-field in the discipline. In an excellent and very recent overview of the literature, Blattman and Miguel (2008) express the widely-held view that the diversity of results and the apparent lack of convergence in the empirical literature on civil conflicts is at least in part due to insufficient theoretical modeling. Hirschleifer and Grossman pioneered the theory of appropriative conflict, where two symmetrical sides, choosing from the same set of actions, optimally allocate their resources to production, soldiering and insurgence, and where conflict arises as an equilibrium outcome when parameters are such that a probability of insurgence success is high.[15] In this tradition, Olsson (2007) presents a predator-prey model where the ruler is assumed to own all resources, while the rebels' claim is predatory, and tests the theoretical predictions for the case of the rough diamond industry. The study is complementary to the one in this paper, in that here the motivation lies in the legitimate resource policy driven claims by marginalized interest groups dependent on the life-sustaining resources.

Most models in this literature are essentially static,[16] while resource rents are exogenous. Prominent empirical studies on the topic of resource-driven civil conflicts, starting with the series by Collier and Hoeffler as part of the World Bank project on the Economics of Civil War, Crime and Violence,

[12] Civil wars in Indonesia, Cambodia, Burma, Liberia and the Democratic Republic of Congo have involved timber. In the Ivory Coast, cacao and cotton, along with diamonds, are documented to have been connected to the conflict. See the report by Global Witness at http://www.globalwitness.org/pages/en/cote_divoire.htm.

[13] See Reuveny and Maxwell (2001), p. 720.

[14] The natural processes by which the environment absorbs part of the industrial impact would correspond to stock depletion. This broad view can accommodate situations where unrelated industrial or extractive activities damage the environment, like in the Niger Delta, while the government fails to let locals share in the resource revenue bounty as compensation for their lost livelihood.

[15] See Neary (1997) for a comparison between rent-seeking and conflict models.

[16] In a recent review, Garfinkel and Skaperdas (2006) point out that 'only the surface of the dynamic effects of conflict has been scratched.' (p. 54.)

report economic opportunity - the ‘greed’ motivation - as the predominant explanation of internal violence. However, many of these results are not robust to the definition of conflict, of resource-dependence or the particular sample of countries or year of analysis.[17] The approach in this paper resembles the ones in Damania and Barbier (2001) and Barbier et al.(2005), who present, respectively, political economy models of renewable and non-renewable resource harvesting and focus on trade policy instruments and resource conversion. This paper differs chiefly in structuring the interaction among three groups of players with distinct objectives and in focusing on resource-based civil conflict. The present model is inherently dynamic, featuring the intertemporal management of a renewable resource (which could be broadly interpreted as *the environment*), endogenizes the resource policy and also allows for an asymmetrical treatment of the government and potential rebel sides.

The rest of this work is structured as follows. The next section looks at the quality of governance as driving policies susceptible to generate discontent and it presents the no-conflict opportunistic government equilibrium in contrast to the the ‘no-corruption’ first best benchmark. The following section allows for internal conflict to be a factor and studies properties of an equilibrium where costly manifestations of discontent factor into the government’s decision making. In addition, the section discusses how resource depletion and the quality of governance may influence the emergence of full scale conflicts. The effects of possibly complementary external conservationist pressure in the form of trade sanctions and aid conditional on resource conservation performance are then analyzed. The third part of the paper summarizes the main findings and concludes.

[17] As Hegre and Sambanis (2006) contend in a recent study that undertakes a ‘global sensitivity analysis’ of these studies p. 509.

1.2 A Political Economy Model of Renewable Resource Exploitation

Many resource-based conflicts around the world are about minerals, yet there are also numerous cases where renewable resources are involved. It is generally considered that - with the exception of water - renewable resources are more likely to generate internal conflicts than international ones, due to the fact that ‘states cannot easily convert cropland, forests and fish seized from a neighbour into increased state power’.[18] Apart from timber, fish stocks and wildlife are also over-exploited across the world, with their management being least effective or non-existent mostly in the unstable areas of the world. Governments in developing countries consistently augment their revenues by granting exploitation rights to domestic or foreign private interests or foreign countries, at times at the expense of the locals.[19]

1.2.1 Peaceful Resource (mis)Management

The three agents in the model are: the government deciding on the exploitation rate of a renewable resource, the extractive industry acting like an organized group to lobby the government for higher than optimal quotas, and the local peasants, each harvesting a subsistence amount of the resource. The paper first looks at the case where conflict is not an option, possibly due to the fact that harvesters cannot resolve their collective action problem. When subsequently allowing for the prospect of conflict to play a role, it is assumed - without modeling that particular game - that harvesters have overcome the free riding obstacle and are able to challenge the government.

The resource exploitation regime is modeled as follows: the industry presents the government with a ‘bribe schedule’ that relates contribution payments to harvesting quotas.[20] The government takes this schedule as given and maximizes its own utility function that depends on the welfare of the sector and the contributions it gets from the big industry to set

[18] Homer-Dixon (1999), p. 138.

[19] Senegal made international headlines in 2006 when it denounced a previous contract that allowed EU vessels to fish in Senegalese waters and that severely depleted fish stocks local fishermen had been dependent upon for generations. The European Union holds similar agreements with most African coastal states, whereby European fishermen are allowed to harvest in African waters for a fixed overall sum that many argue understate the true environmental cost.

[20] Similar, e.g. to Grossman and Helpman (1994).

the quota at a high level.[21] While the industry values the proceeds from harvesting, the locals' very existence is linked to the resource.[22] The way this feature is modeled here is the following: the individual utility function of a local harvester is equal to the amount of the resource required for subsistence $\bar{h}$, less the disutility of effort required to harvest it. Peasants are heterogeneous with respect to their harvesting ability q_i and their harvesting function equals the product of combining three inputs: the harvesting ability, the level of the resource stock and labour: $\bar{h} = q_i S l_i$. Their preferences are represented by a (disaggregated) utility function of the following form:

$$u_i(\bar{h}, l_i) = \bar{h} - l_i = \bar{h} - \frac{\bar{h}}{q_i S}.$$

Peasants 'migrate'[23] or pursue outside opportunities, represented by a unit labour wage w,[24] treated as exogenous, if they can improve their payoff. In the present context this means working less in order to earn the subsistence amount $\bar{h}$. The individual peasant i remains a harvester as long as the utility she would get by taking the alternative opportunity does not exceed the status quo payoff: $u_i(\bar{h}, l_i) \geq u_i(\bar{h}, l_i')$, equivalent to $l_i \leq l_i'$ or $\frac{\bar{h}}{q_i S} \leq \frac{\bar{h}}{w}$ which implies

$$q_i \geq \frac{w}{S},$$

and takes the superior outside option otherwise. As the resource gets depleted, the local resource-dependent population decreases, and so does their group strength.[25]

Assuming that harvesting ability is uniformly distributed in the total peasant population on an interval defined by two extreme values that are

[21] The monetary contribution paid by the industrial sector to the government is called 'bribe'. To be exact, however, this terminology is only accurate from the point of view of the government, who embezzles the quota rights. From the firm's point of view, 'the bribe' is just the cost of obtaining the harvesting licence. In theory, this should be illicit from the company's perspective when the amount paid to the government would not be enough to compensate for the true social welfare cost of harvesting. However, no restrictive assumptions are made in this respect here.

[22] This responds in part to some critics of the economics models of conflict contending that the exclusively extrinsic, payoff-motivated players are incompatible with the many documented instances of *intrinsically motivated* actors. See e.g. Cramer (2002) 'Homo Economicus Goes to War'.

[23] This does not have to involve physical migration, only disconnect from the resource.

[24] The amount w can be thought of as the minimum wage in the neighbouring city, region or country where migration is feasible.

[25] The decrease is less than proportional if one assumes harvesting ability is positively correlated with fighting ability.

determined by an initial distribution and past migrations, $q_i \sim U[\underline{q}, \bar{q}]$, the fraction of the normalized initial population that remains at every level of the resource stock is $L(S,w) = (\bar{q} - \frac{w}{S})$, while the mass of city migrants equals $(\frac{w}{S} - \underline{q})$.[26] The rural harvesting population decreases as the resource is depleted and it becomes increasingly difficult to provide sustenance to everyone, and also decreases when outside opportunities become more attractive: $L_S > 0$ and $L_w < 0$.

Suppose the peasant population matters for the government, for instance in their role as voters, a common assumption in the political economy literature. Then, even an opportunistic regulator 'cares' about social welfare, along with bribes. The aggregate utility of small harvesters is the sum of the utilities of locals remaining in the rural area and the city migrants: $u = u^r + u^c$.[27] To obtain the aggregate utilitarian u^r, integrate the individual utilities of the remaining locals on the relevant support as follows:

$u^r = \int_{\frac{w}{S}}^{\bar{q}} u_i dq_i = \int_{\frac{w}{S}}^{\bar{q}} (\bar{h} - \frac{\bar{h}}{q_i S}) dq_i = \bar{h}(\bar{q} - \frac{w}{S}) - \frac{\bar{h}}{S} \ln \frac{\bar{q}S}{w}$. Similarly, adding the welfare of migrants yields

$u^c = \int_{\underline{q}}^{\frac{w}{S}} (\bar{h} - \frac{\bar{h}}{w}) dq_i = \bar{h}(1 - \frac{1}{w})(\frac{w}{S} - \underline{q})$, so that the aggregate utility of peasants can be written as:

$$U(S) = \bar{h}(\bar{q} - \underline{q}) - \frac{\bar{h}}{S} \ln \frac{\bar{q}S}{w} - \frac{\bar{h}}{w}(\frac{w}{S} - \underline{q}).$$

It follows that the marginal utility of a resource unit is: $U_S = \frac{\bar{h}}{S^2} \ln \frac{\bar{q}S}{w} > 0$, and the second derivative $U_{SS} = \frac{\bar{h}}{S^3}(1 - 2\ln \frac{\bar{q}S}{w}) < 0$.

The industrial and small scale harvesters always coexist in this model. The paper assumes for simplification that the profit function of the industrial sector is such that profits are positive or the firm is active for all relevant stock levels and prices. In other words, the extraction technology is assumed to be 'advanced enough' to yield positive profits even at low levels of the resource. For tractability it is assumed that all agents discount the future at the same rate. The resource management instrument chosen by the government is a quota on harvesting, which is the predominant form of actual resource and environment protection policies worldwide.[28]

[26] Notice that the formula for the number of locals remaining is robust to subsequent migrations: as the low ability types leave, the lower bound of the ability interval moves to the right, yet the upper bound remains fixed.

[27] If the peasant 'migration' is physical and the resource is administered by a local government, the utility of city migrants will not appear in that government's objective. In this particular case, the results are the same, while having a simpler expression.

[28] The quota does not bind the small-scale harvesters due to the impossibility of enforcement and/or the fact that the government trusts the 'environmentally responsible'

We are interested in how the quality of governance affects the environmental outcome. As a benchmark, consider first the first-best case where there is no corruption. Let $\pi(p, H, S)$ be the industry's total profit, increasing in all arguments: the price of the final resource good, the harvesting quantity and the stock of the resource, since harvesting costs are assumed to increase with resource scarcity. Denote by δ the rate of time preference in the society, and by $F(S)$ the natural growth function of the resource, which is assumed to be strictly concave. An *honest government* maximizes the discounted present value of a social welfare function of the following form:

$$\underset{Q}{Max} \quad \int_0^{\infty} e^{-\delta t}[\pi(p, H, S) + U(S)]dt \text{ subject to } \dot{S} = F(S) - H - \bar{H}$$

and $H \leq Q$.

The first constraint is represented by the growth of the stock, which depends on a natural growth function F(S) and the combined harvesting H and $\bar{H}$, where the latter represents the subsistence amount harvested on aggregate by the local peasants: $\bar{H}(S) = \bar{h}(\bar{q} - \frac{w}{S})$. The second constraint provides that industrial harvesting H does not exceed the total allowable catch Q and will be binding at optimum. I assume lump-sum transfers are ruled out (for instance in the presence of a significant marginal cost of public funds), and the only distributional channel is via the resource policy.

Optimal harvesting regulated by an honest government without the possibility of conflict satisfies the following steady-state decision rule, as detailed in the Appendix, section (1):

$$(F_S - \bar{H}_S) + \frac{\pi_S + U_S}{\pi_Q} = \delta. \tag{1.1}$$

This is a version of the augmented *modified golden rule* of renewable resource exploitation introduced by Clark and Munro (1975).[29] The last term on the left-hand-side constitutes the marginal stock effect (MSE). This arises since in this setting welfare depends not only on the flow of harvesting, but also on the stock of the resource via its effect on harvesting costs for the industry as well as for the locals. Drawing a parallel to capital theory, the above equation states that it is optimal to invest in the resource by abstaining from harvesting until the net marginal resource yield $(F_S - \bar{H}_S)$,

locals not to over-deplete the resource, or the fact that the local subsistence harvesting is of a much lower order of magnitude than the Total Allowable Catch (TAC) or, like in many communities in North-America, the existence of treaties which allow harvesting privileges for locals.

[29] See also Munro (1979), p. 5.

augmented to account for the effects on industry profits and locals' utility, equals the social rate of discounting the future. In other words, the left hand side represents the social return from conserving one unit of the resource, while the right hand side is the social cost of doing so. Alternatively, the MSE can be re-written as the society's 'marginal rate of substitution' between keeping the resource *in situ* and harvesting it: if W^h is the welfare function of the honest government described above, $W^h_Q = \pi_Q$ and the marginal welfare effects of harvesting and resource level are calculated as: $W^h_S = \pi_S + U_S|_{H=H^*}$, then the marginal stock effect $MSE = \frac{W^h_S}{W^h_Q}$. The expression in (2.1) yields a unique stationary resource stock level achieved under an honest government, which is denoted by S^h.[30]

When corruption is present, there is scope for strategic industry-regulator interaction. To keep things standard, the *menu auction* introduced by Bernheim and Whinston (1986) is assumed as framework for the game, as it has served as the workhorse model for most recent political economy studies, starting with Grossman and Helpman (1994). The extractive interest group presents the government with a bribe schedule that relates contributions to policy alternatives. The government then chooses the policy measure by trading off bribe revenues and losses in welfare brought about by the socially inefficient choice induced by the contributions. The firms harvest according to the set quota level and pay the corresponding bribe to the government. Denoting by $G = W + \beta B$ the utility function of the government, as a sum of the social welfare and the value of the contributions, and by π the gross industry profit, Bernheim and Whinston (1986) show that the 'truthful' equilibrium harvesting has to satisfy the following: $(C_1) : Q = argmax_H\{G\}$ and $(C_2) : Q = argmax_H\{G + \pi\}$.[31] If the above conditions were not satisfied, it would be possible for the firm to adjust its contribution schedule so as to induce the government to maximize the joint surplus, while keeping most of the gain for itself.[32]

An implicit assumption is that all agents are forward-looking, and that property rights are enforced.[33] This simplification allows one to avoid diverting the analysis towards free riding incentives and focus on conflict instead.[34] The local harvesters have no incentives for poaching, since they only take the minimum subsistence amount, while the large extractive industry pur-

[30] See Clark and Munro (1975), p. 95.

[31] See Lemma 2, op.cit., p. 10. A similar approach is adopted in Barbier et al.(2005).

[32] See for instance Grossman and Helpman (1994), p. 839.

[33] Commercial exploitation of resources with a government-issued licence has to imply some system of property rights is in place.

[34] See e.g. Hotte et al. (2000) for an endogenous property rights enforcement model.

chases its harvesting rights from the government. Resource overexploitation by extractive companies is often sanctioned by successive opportunistic officials, thus the briber becomes practically immune to expropriation due to the complicity of the regulator. Under these conditions, it can be assumed that the agents are forward-looking and solve an optimal control problem.

Condition (C_1) above amounts to maximizing $G(W,B) = W + \beta B$, where W is the aggregate welfare, B is the bribe and $(\beta - 1)$ a measure of corruption. The weight attached to the bribe entering government's utility function is higher than unity $\beta > 1$ when the government is corrupt, since it values a unit of income in its hands more than when in the hands of the public. The government's problem is then the following:

$$\underset{Q}{Max} \quad \int_0^{\infty} e^{-\delta t}[\pi(p,S,Q) - B(Q) + \beta B(Q) + U(S)]dt \tag{1.2}$$

subject to $\dot{S} = F(S) - Q - \bar{H}(S)$.

Since total firm profits are increasing in the amount harvested H on the relevant range and the bribe schedule is increasing in Q, the firm will always have an incentive to lobby for a larger quota and the implicit constraint $H \leq Q$ holds with equality. The solution to the optimal control problem is presented in the Appendix section (2) and it yields a general decision rule of the following form:

$$(\delta - F_S + \bar{H}_S)[\pi_Q + (\beta-1)B_Q] - \pi_{QQ}\dot{Q} - (\beta-1)B_{QQ}\dot{Q} - \pi_{QS}\dot{S} = \pi_S + U_S. \tag{1.3}$$

Similarly, according to condition (C_2) above, the optimal harvesting quota and bribe tuple has to also maximize $\{\pi + G\}$:

$$\underset{Q}{Max} \quad \int_0^{\infty} e^{-\delta t}[2\pi(p,S,Q) - 2B(Q) + \beta B(Q) + U(S)]dt \tag{1.4}$$

subject to $\dot{S} = F(S) - Q - \bar{H}(S)$, which is shown in the Appendix section (3) to imply:

$$(\delta - F_S + \bar{H}_S)[2\pi_Q + (\beta-2)B_Q] - 2\pi_{QQ}\dot{Q} - (\beta-2)B_{QQ}\dot{Q} - 2\pi_{QS}\dot{S} = 2\pi_S + U_S. \tag{1.5}$$

In a steady-state equilibrium, conditions (1.3) and (1.5) above become respectively equivalent to: $(\delta - F_S + \bar{H}_S)[\pi_Q + (\beta-1)B_Q] = \pi_S + U_S$ and $(\delta - F_S + \bar{H}_S)[2\pi_Q + (\beta-2)B_Q] = 2\pi_S + U_S$. Solving for the optimal 'bribing intensity' $B_Q = \frac{1}{\beta-1}(\frac{\pi_S + U_S}{\delta - F_S + \bar{H}_S} - \pi_Q)$ from the first and substituting into the second yields the following truthful-contribution equilibrium decision rule in the steady state:

$$(F_S - \bar{H}_S) + \frac{\beta\pi_S + U_S}{\beta\pi_Q} = \delta, \tag{1.6}$$

where recall that $\beta > 1$ because the government is assumed to be corrupt.[35] This expression yields implicitly the steady state stock of the resource under a corrupt government S^c. The government allows industrial harvesting to deplete the resource up to a level at which the discount rate just equals the net marginal benefit of conservation to the government, with the industry profits being assigned a higher weight than the locals' utility. Substituting the optimal exploitation rule in the bribe intensity expression yields: $B_Q = \pi_Q - \frac{\pi_S}{\delta - F_S + \bar{H}_S}$, which is the adapted expression for local truthfulness: the gradient of the bribe schedule coincides with the marginal contribution to the lobby group's profit of the extra unit of harvesting, taking into account the stock externality of resource depletion.[36] The following intermediate results are instructive for further analysis.

Lemma 1: *Bribing intensity increases as the stock gets depleted.*

While by applying (2.6) it is easy to see that $B_Q > 0$, that is the bribe schedule increases in the quota, the bribing intensity can also be expressed as: $B_Q = \frac{U_S}{\beta} \cdot \frac{1}{\delta - F_S + \bar{H}_S}$. Then the following cross-partial derivative of the bribe schedule $B_{QS} = \frac{\beta}{(\delta - F_S + \bar{H}_S)^2}[U_{SS}(\delta - F_S + \bar{H}_S) + U_S(F_{SS} - \bar{H}_{SS})]$ is negative under the assumption of negative second partial derivatives of the resource growth and profit functions with respect to stock. In order for the regulator to respond to its policy preferences, the industrial lobby needs to keep it weakly better off than under the first best case. When the resource is more scarce, the necessary efforts by the firm to increase the harvesting quota by one unit are larger, due to the need to compensate for a sharply falling social welfare function.

Lemma 2: *A more myopic government is less conservationist.*

This result is intuitive, and the proof provided in the Appendix section (4)(i) is immediate. Higher discounting of future periods implies larger

[35] The problem is equivalent in the steady state with one in which the government maximizes a social welfare function in which industry profits enter with a weight of β, while the aggregate utility function of the locals enters with a unitary weight.

[36] This is, for instance, the equivalent of condition (9), p. 839 in Grossman and Helpman (1994). By contrast, a myopic industry would prefer a quota satisfying the equality between the bribing intensity $B_Q = \pi_Q$, as a result of the static maximization of their harvesting profits net of the bribe: $\Pi(p, Q) - B(Q)$. The implicit assumption is that the firm's optimal harvesting level is below the government quota, due to the government's additional objectives.

weights attached to harvesting-derived present payoffs and consequently leads to a lower steady-state resource stock level.

Lemma 3: *If the marginal stock effect under one resource management regime is larger than under a different one at all possible stock levels, then the equilibrium stock level in the first case is also larger than in the second, ceteris paribus.*

In short: if 1 and 2 denote different regulator objectives and $MSE_2(S) > MSE_1(S)$, for all feasible levels of stock ($\forall S \in [0, K]$), then $S_2^* > S_1^*$. A proof by contradiction is provided in the Appendix section (4)(ii) and this result facilitates the comparisons of equilibrium stock levels across the different policy environments.

Comparing the equilibrium stock level set by a self-interested government with the 'efficient' level set by an honest government, i.e. equations (2.1) and (2.6) above, yields the following result:

Proposition 1: *The steady-state equilibrium stock level when harvesting is regulated by a corrupt government is always below that obtained under an honest government.*

Proof: provided in the Appendix section (5).

The proof relies on Lemma 3 and on the fact that the corruption coefficient is larger than unity. This proposition establishes the dynamic natural resource counterpart of the Lopez and Mitra (2000) result, which states that pollution is higher in corrupt regimes, obtained in their case as a Nash bargaining outcome of a game between the government and the private firm.[37]

This finding is not as banal as it may seem at first, since an established result in the field of natural resource economics is that profit maximization and efficient resource conservation are not incompatible under the assumption that property rights are well-defined.[38] The optimal decision equation for a corrupt government can be re-written as: $F_S - \bar{H}_S + \frac{\pi_S + U_S}{\pi_Q} = \tilde{\delta}$, where $\tilde{\delta} = \delta + \frac{U_S}{\pi_Q}(1 - \frac{1}{\beta})$ is above δ for all values of the corruption coefficient larger than one. The presence of corruption is equivalent to the government being more myopic in its resource policy making. Intuitively, the resource is valuable for a group to which the corrupt government is attaching a lower weight. In the first best case when the regulator is honest, the presence of small harvesters leads to an equilibrium stock that is larger than the profit-maximizing level. When the regulator is corrupt, the policy influence of

[37] The result also corroborates the findings in Barbier et al (2005) for the case of resource conversion, and those in Fredriksson and Svenson (2002) for environmental regulation.

[38] '...the monopolist is the conservationist's friend.' according to Solow (1974), p. 8, among others.

locals is weakened and the second-best income transfer that takes place via the resource policy entails a lower steady-state level of stock. It is evident in the optimal decision rule formula that the opportunistic government effectively attaches a weight of $\beta > 1$ to terms related to industry profits, while the harvesters' utility is assigned a unitary coefficient. Hence, the resource outcome is unambiguously less conservationist than under an honest government.

Thus far the behavior of resident small harvesters has been restricted to each consuming passively a subsistence amount $\bar{h}$ of the resource good. Therefore, their channel of influencing the environmental outcome was, by design, limited to the inclusion of their group utility in the social welfare function.[39] In what follows, the harvesters will be in the position to exert additional influence on the government, as they can generate unrest which is costly for the government.

1.2.2 Internal Pressure: the Shadow of Conflict

Assume now that the locals have the option of manifesting their discontent by civil unrest or starting an insurgency.[40] The trade-off for the government is between allowing for more resource depletion in exchange for monetary contributions from the industry and augmenting the discontent of the locals.

There are two features of the present view of conflict that should be mentioned here. First, civil tensions are modeled in the paper not as a discontinuity in the government's utility profile, but rather as a process that can be tolerated by a corrupt government as 'a cost of doing business'. This allows one to look at the interplay between the threat of conflict and policy outcomes, when one interest group is not organized as a lobby, but rather as 'rebels'. The specter of conflict becomes relevant not due to direct appropriation of the resource, but rather via policy channels, through the higher-than-optimal harvesting quota set by the corrupt government. Unlike other papers in the literature[41] which assume perfectly myopic agents that deplete the resource up to a conflict-generating threshold, in this paper corruption

[39] The above harvesters only count as voters, which is the reason why even a corrupt government takes their concerns into account when devising the resource management policy, or alternatively they could 'vote with their feet' by migrating.

[40] This situation can result from small harvesters resolving their collective action problem. Using the language of Acemoglu and Robinson (2005), the small harvesters have *de facto* political power in this setting.

[41] Maxwell and Reuveny (2000), Homer Dixon, Gledisch, among others.

is the actual trigger of conflict. Consequently, the issue becomes one of the *degree* of civil unrest, where all-out civil war erupts when violence reaches a certain level, which may or may not be known by the government. This is consistent with the empirical analysis in the second chapter, where conflict is defined in relation with a certain 'battle-related deaths'-threshold. This will be modeled here as an expected cost of conflict exceeding an arbitrary threshold.

A second distinguishing feature of conflict (as modelled here) is that it is asymmetric. Most theoretical models of conflict feature two parties facing symmetric problems of allocating scarce resources - usually labour, bounded by population sizes - between productive and bellicose uses. However, in episodes of resource-based violence it is far more common to witness one group revolting against the government. Civil conflicts are defined in the leading global data collection projects as invariably involving the government.[42] The interaction between the two parties is then asymmetrical, with the government having - in principle - non-military options at its disposal to either alter the contentious resource policy in order to appease the potential rebels, or to deter them by investing in the military and thus avoid an all-out conflict.

The discontent of the locals vis-à-vis the government-sanctioned exploitation of resources as modeled here corresponds to 'frustration-aggression' theories based on relative deprivation: violence arises as a result of a discrepancy between actual payoff and perceived merit.[43] Small harvesters' maximum potential payoff corresponding to the case when they rebel and win a conflict against the government is what they obtain when they actually set the harvesting policy themselves. It is reasonable to assume here they prefer zero industrial harvesting, given that there are no employment and income spillovers from the industrial harvester of the resource. The stylized fact that the local populations hardly ever draw any benefits from industrial resource extraction is confirmed by ample case-study evidence, and is mostly based on widespread use of capital-intensive exploitation technology and of a relatively skilled migrant workforce.[44]

Therefore, the ideal payoff of peasant harvesters is $U^* = U(S^*)$, where S^*

[42] UCDP defines conflict as: 'a contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25 battle-related deaths.' See http://www.prio.no/cwp/armedconflict/current/Codebook_v4−2006b.pdf for more details.

[43] For a thorough exposition of these concepts in the context of resource conflicts see Homer-Dixon (1999), p. 136.

[44] See Renner (2002), p. 40.

denotes the 'pristine' state of the resource where the only extraction is done by subsistence harvesters, or S^* solves $F(S) = \bar{H}(S)$.[45] The propensity to rebel ρ is defined as a function of the stock-related *objective discontent* of the local peasants, measured as $\Delta U = U^* - U$. The likelihood of social unrest depends on the resource-related motivation of the locals and it is represented by the following function defined on the continuous domain between zero and one:

$$\rho(S) = \frac{U^* - U}{\Delta U + U} = \frac{\Delta U}{U^*}.$$

Using the aggregate utility function defined before, $\rho = \frac{1}{U^*}[\bar{h}(\frac{1}{S} - \frac{1}{S^*}) + \bar{h}(\frac{\ln \frac{\bar{q}S}{w}}{S} - \frac{\ln \frac{\bar{q}S^*}{w}}{S^*})]$ and $\rho_S = \frac{-1}{U^*}\frac{\bar{h}}{S^2}\ln\frac{\bar{q}S}{w}$. Consequently $\rho_S = -\frac{U_S}{U^*} < 0$, so unrest is more likely as the resource gets more depleted. Appeasing or deterring unrest is costly. Assume that the government's utility drop induced by the locals' discontent is an increasing function of the size of the peasant population L: $C(L(S,w)) = \gamma L(S,w) = \gamma(\bar{q} - \frac{w}{S})$, with γ a parameter: the cost of 'dealing' with the insurgents is proportional to their number. This is in fact assuming the simplest constant return to scale technology of conflict.

Maximizing the government utility under these circumstances entails taking into account the costs of civil unrest:

$$(C_1^w) \ \underset{Q}{Max} \quad \int_0^\infty e^{-\delta t}[\pi(p,S,Q) - B(Q) + \beta B(Q) + U(S) - \rho(S)C(L(S,w))]dt$$

while maximizing the joint industry-government payoffs is equivalent to:

$$(C_2^w) \ \underset{Q}{Max} \quad \int_0^\infty e^{-\delta t}[2\pi(p,S,Q) - 2B(Q) + \beta B(Q) + U(S) - \rho(S)C(L(S,w))]dt,$$

subject to the familiar resource constraint.

The solutions to the two problems are given in the Appendix section (6) and in a steady-state equilibrium the following obtain:

$(\delta - F_S + \bar{H}_S)[\pi_Q + (\beta - 1)B_Q] = \pi_S + U_S - \rho_S C - \rho C_L L_S$ and $(\delta - F_S + \bar{H}_S)[2\pi_Q + (\beta - 2)B_Q] = 2\pi_S + U_S - \rho_S C - \rho C_L L_S$.

Expressing the 'bribing intensity' as $B_Q = \frac{1}{\beta-1}(\frac{\pi_S + U_S - \rho_S C - \rho C_L L_S}{\delta - F_S + \bar{H}_S} - \pi_Q)$ from the first equation and substituting into the second yields the modified augmented golden rule of renewable resource exploitation under a corrupt government when conflict is possible as:

$$(F_S - \bar{H}_S) + \frac{\beta\pi_S + U_S - \rho_S C - \rho C_L L_S}{\beta\pi_Q} = \delta. \tag{1.7}$$

[45] Alternatively, the ideal stock level could equal the long-run optimum as regulated by an honest government.

There are two opposite effects induced by the discontent-fueled unrest. On one hand, the cost of keeping unrest under control induces the government to effectively regulate a higher level of the resource stock, while on the other hand it has an incentive to draw the resource level further down, since this weakens the local (potential rebel) workforce, thus decreasing the cost of discontent. The net effect of allowing for the possibility that the locals may manifest their 'grievance' in a costly way for the government depends on the relative strength of the *discontent* and *migration* effects.

Comparing the resource stock implied by equation (1.7) with the one in (1.6) yields the following: When the relative increase in discontent caused by a unit decrease in the level of resource stock exceeds the corresponding cost savings brought about by migration, so that the net effect of depletion entails a positive cost to the government or: $-\rho_S C - \rho C_L L_S > 0$, the marginal stock effect with conflict is higher than its no-violence counterpart. The intuition is the following: when local harvesters pose a credible challenge by making it costly for the government to opportunistically deplete the resource, their implicit policy weight increases. The ensuing regulation is then bound to be more conservationist.

Proposition 2: *The specter of conflict based on resource-related discontent of local harvesters under a corrupt government has conservationist consequences when the 'discontent' effect dominates, i.e. for a low ideal stock level (S^*) and low outside opportunities (w) and high maximum harvesting ability $\bar{q}$. The equilibrium stock decreases if the 'migration' effect dominates, for opposite values of the parameters.*

Proof: provided in the Appendix section (7) and below.

The Appendix section (7) shows the condition under which costly discontent increases the equilibrium level of the resource stock takes the following form: $G(S) = \theta S + (\frac{\bar{q}S}{w} - 2) lnS - \phi > 0$, where $\theta = (\frac{\bar{q}}{w} \ln \frac{\bar{q}}{w} + \varepsilon)$, $\phi = 2 \ln \frac{\bar{q}}{w} - 1$ and $\varepsilon = \frac{\ln \frac{\bar{q}S^*}{w} + 1}{S^*}$. While an analytical solution cannot be obtained, the graph in Figure 1.1 shows - via a numerical simulation - that satisfying the inequality entails that the steady-state optimal stock level exceeds a certain threshold level S'.[46] The discontent effect curve shifts up when $\bar{q}$ is higher and when w is lower.[47] The migration effect shifts down when w and S^* are lower.[48] Thus, it can be seen that the threshold value

[46] Notice that both functions in the first graph are constrained to be positive here.

[47] The 'discontent effect' curve plotted is $-\rho_S C(L(S, w))$ and its non-monotonicity in S is driven by the fact that the marginal propensity to rebel is decreasing in S, while the cost of 'dealing' with the rebellion is increasing in the number of locals, which in turn is increasing in S.

[48] This effect is also non-monotonic, since the propensity to rebel is decreasing in S,

S' is lower, thus easier to fulfill for higher θ, implying higher $\bar{q}$ and lower w, as well as for higher ε, which entails a lower S^*, since $\frac{\ln S^*}{S^*}$ decreases in S^*.

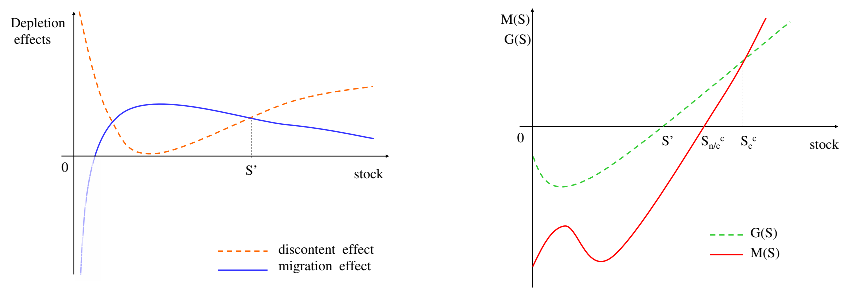


Figure 1.1: Discontent and Migration Effects

According to (1.6), the optimal stock level without conflict is given by $M(S) = (\delta - F_S + \bar{H}_S)\beta\pi_Q - \beta\pi_S + U_S = 0$, while the optimal stock with conflict arises at the intersection of $M(S)$ and $G(S)$, as shown in the second graph.[49] The condition that the equilibrium stock level is 'large enough' is also more likely for a higher $S^c_{n/c}$, which entails that the corruption coefficient β, the ratio $\frac{r}{K}$ and the price of the resource good p are all low.

If the migration effect exceeds the discontent effect, the marginal stock effect and the equilibrium stock are smaller when conflict is possible. In this case the government has an incentive to purposefully deplete the resource in order to drive out the potentially inconvenient locals. This occurs when the ideal stock level and outside opportunities are high and/or when the local harvesters have a high harvesting ability. Under full information, harvesters would consequently have less of an incentive to organize and mount pressure on the government, knowing the result would be an acceleration of resource depletion and implicitly a decrease of their utility.

Comparing the marginal stock effect implied from (1.7) to the one obtainable under an honest government (1.1) opens the somewhat surprising possibility that:

Corollary 1: *Under the specter of corruption-triggered conflict, an opportunistic government can be even more conservationist than the honest*

while the marginal cost is increasing in S.

[49] The simulation is based on logistic resource growth with intrinsic growth rate r and carrying capacity K: $F(S) = rS(1 - \frac{S}{K})$ and the simplest industry profit function $\pi(p, Q, S) = (p - \frac{c}{S})Q$.

government.[50]

This may occur when the government is not 'too corrupt' relative to parameters: $\beta < 1 - \frac{\rho_S C + \rho C_L L_S}{U_S}$, which after plugging in the functional forms introduced above is equivalent to $\beta - 1 < \frac{\gamma}{h}$. Such a situation is facilitated when a high marginal cost of waging war for the government combines with a not too large subsistence amount and relatively low corruption to yield a more conservationist policy outcome.

An important motivation of this paper has been to understand the effect of resource policy and governance quality on resource-based civil conflicts. Here the focus is on the effect of corruption on the likelihood of conflict, given 'official corruption' as related to the exploitation of natural resources is one of the main justifications of such rebellions. As mentioned above, civil unrest is called a civil *conflict* when a certain intensity of violence is reached. This is represented here by the expected cost of conflict, denoted by $P(S) = \rho(S)C(L(S, w))$. The larger P, the more likely it is that a discontent-motivated civil conflict will occur in this setting. Differentiating this function with respect to the stock level of the contentious resource S, the following obtains:

$$P_S = \rho_S C + \rho C_L L_S.$$

While the locals' discontent increases as the level of stock goes down, the requirements of subsistence consumption fosters emigration and weakens the rebellion threat, such that the probability of conflict increases in corruption for some levels of the resource stock and it decreases in corruption for others. In this setting *discontent-driven grievance-based resource conflict* arises when $P_S < 0$, or when:

$$-\rho_S C > \rho C_S. \tag{1.8}$$

While (1.8) is an implicit relationship, it has an intuitive interpretation. When the increase in discontent brought about by a one-unit decrease in stock level is more than the marginal cost savings associated with the outward migration of potential rebels, the resulting likelihood of conflict increases, situation which is more likely when the equilibrium resource level is sufficiently high, which in turn requires parameters to be as described in Proposition 2. The opposite occurs when the migration effect dominates, as the government may be more able to keep the civil unrest under control and prevent it from erupting into a full-blown conflict.

[50] This result assumes conflict is only possible when the government is opportunistic, or $S^* = S^h$ emphasizing the 'grievance' aspect of this rebellion: insurgency is legitimate only against a corrupt government.

As the corruption coefficient only influences the probability of conflict via the regulated level of depletion,[51] its partial effect can be written as:

$P_\beta = (\rho_S C + \rho C_L L_S)S_\beta = P_S S_\beta$.

When the discontent effect dominates, corruption increases the likelihood of conflict, since $P_S < 0$ and $S_\beta < 0$.[52] When the migration effect dominates, the impact of corruption of the likelihood of conflict is unclear, since $P_S > 0$, but the sign of S_β is ambiguous.

To analyze the manner in which the quality of governance affects this marginal effect of depletion on the likelihood of resource-based civil conflicts, take the cross-partial derivative of P with respect to the corruption coefficient β:

$$P_{S\beta} = (\rho_{SS} C + 2\rho_S C_L L_S + \rho C_L L_{SS} - \theta_{SS})S_\beta. \tag{1.9}$$

Since when the discontent effect exceeds the migration effect the equilibrium level of the resource stock is decreasing with the regulator corruption ($S_\beta < 0$), the impact of corruption on the marginal effect of depletion on the likelihood of conflict is a function of the sign of the bracketed expression in (1.9) which equals P_{SS}. Appendix section (9) shows that $P_{SS} > 0$ when the equilibrium level of stock exceeds S'', condition which is more restrictive than the one stipulated in Proposition 2 above, yet is also more likely to be satisfied for high $\bar{q}$ and low w and S^*, as well as low β, p and $\frac{r}{K}$. Under such conditions, case in which $S_\beta < 0$, the result that $P_{S\beta} < 0$ obtains. In words:

Corollary 2: *The marginal effect of depletion on the likelihood of conflict can decrease with corruption as long as harvesting ability and carrying capacity of the environment are low, outside opportunities, ideal stock level, governmental corruption, price of the product and intrinsic growth rate of the resource are high.*

This may help understand why the more corrupt places are not always the ones witnessing episodes of resource-based civil conflict, even though 'governmental corruption' ranks high in the motivation list of insurgents.

1.2.3 External Pressure: Trade and Aid

[51] Alternatively, one can imagine the quality of governance entering directly into a discontent function for the local harvesters, although this would entail measurement issues related to the difference between real and perceived levels of corruption.

[52] See the Appendix section (8) for the derivation.

Despite their name, resource-based civil conflicts, are rarely purely 'domestic',[53] but rather depend on international trade, finance and aid networks. In the present model this international dimension is represented by the possibility of trade measures against the regime and of international transfers or aid.

The optimal harvesting expression under a corrupt government under the threat of conflict presented in (1.7) allows for a few comparative statics that shed light on the impact of international pressure on the quality of the domestic resource extraction regime. In particular, the effect of trade sanctions and international aid, which are often the measures of choice to achieve such purposes can be readily derived. In peace time, the large scale industry exports the good. Assume, as it is common in the literature,[54] that the effect of *international sanctions* against a regime that overexploits the environment is to reduce instantaneously the producer price from commercializing the resource good. Then, the sole effect of the resource-related sanctions here is to decrease the profits of the firms π. Sanctions can be modeled as an ad-valorem import tariff for the resource good (τ), that can be varied from zero to infinity, to increase the severity of the restriction. Then profits can be written as $\pi(p', S, H)$, where $p' = p(1-\tau)$.[55] The goal of the sanctions is then reached if the long-run equilibrium level of the resource stock is higher as a result of their imposition. The following holds:

Proposition 3: *A drop in profits caused by resource-targeted international trade sanctions will, ceteris paribus, have a conservationist effect on the resource as long as the the conditions for $P_{SS} > 0$ are satisfied.*

Proof: see below and in the Appendix section (10).

Differentiating expression (1.6) implicitly with respect to the price of the resource export p yields, upon further transformation:

$$\frac{\partial S}{\partial p} = \tag{1.10}$$

$$\frac{(\delta - F_S + \bar{H}_S)\beta\pi_{QS} - \beta\pi_{sp}}{\beta\pi_Q(F_{SS} - \bar{H}_{SS}) + \beta\pi_{SS} + U_{SS} - \rho_{SS}C - 2\rho_S C_L L_S - \rho C_L L_{SS} - (\delta - F_S + \bar{H}_S)\beta\pi_{QS}}.$$

As discussed in the Appendix section (10), the denominator is negative if $P_{SS} > 0$ equivalent to $S > S''$, due to the concavity of the utility, profit and

[53] Le Billon (2000), points to globalization as responsible for the increased duration of such conflicts, due largely to easier financing, arms trade and trade in illicit resources (p. 3).

[54] See, for instance, Damania and Barbier (2001).

[55] Note that, absent a domestic market for the resource good, an equivalent effect is observed when there is a negative shock to the international price of the resource, or a hike in the extraction costs due, perhaps, to an increase in the price of an essential input.

resource growth functions. In addition, notice that when marginal profit is independent of the price ($\pi_{sp} = 0$), the numerator is positive, and therefore, the equilibrium stock level is decreasing with price. The last assumption holds for the family of profit functions for which harvesting costs are not a function of price and harvested quantity is independent of the stock. The same result holds, nevertheless more generally, when, $\pi_{sp} \neq 0$[56] but $\frac{\pi_{Qp}}{\pi_Q}(\beta\pi_S + U_S) > \beta\pi_{sp}$, where the latter inequality is shown in the Appendix section (10) to hold whenever $P_S < 0$, or $S > S'$.[57]

In this case, sanctions work to conserve the resource if they result in effective producer price reductions. Intuitively, sanctions increase the attractiveness of 'investing' in the resource stock by lowering the opportunity cost of conservation. In the political game, lower unit profits translate - since the optimal bribe is truthfully reflecting the marginal effect of increased quota on profits - into lower bribes, thus inducing the regulation of lower harvesting quotas, and has an effect similar to a decrease in corruption. In short, sanctions lower the attractiveness of the prize in the lobbying game. This finding extends to this particular political-economy framework the established result that in a one-species setting and where an independent habitat value is not considered, international sanctions work to increase the long-run stock of the resource.[58] As emphasized in the literature on the conservationist effect of international trade measures, ambiguous or perverse resource stock effects are only obtained when sanctions effectively change the management regime to one of open access, or when the resource becomes a nuisance as an effect of sanctions and the more profitable alternative use of its habitat renders over-depletion or even extinction optimal.

International aid conditional on implementing a certain type of resource management is another possible way to externally influence a country's resource extraction policy.[59] Recently, the global warming debate has fostered the emergence of many such new initiatives which provide grants in

[56] In the present case the harvested amount depends on the stock level since it is equal to the regulated TAC which is determined as the argument the maximizes the social welfare function and the joint regulator-client surplus.

[57] Except for peculiar specifications where production costs depend on final good prices.

[58] This result appears, for instance, in Schulz (1996) and Barbier and Schulz (1997) and is contrary to a series of papers by Swanson (1993), which claim sanctions are an ineffective policy.

[59] Examples are: the Global Environmental Facility (GEF), which provides grants for nature protection, and *debt-for-nature swaps*, whereby a conservationist agency and/or creditors of a developing country agree to sponsor conservationist policies. See also Damania and Barbier (2001), p. 16.

return for conservation.[60] While unconditional transfers might have adverse rent-seeking effects on the host economy characteristic to revenue booms, conditional aid may be successful in effecting positive change. Provided monitoring capabilities exist, the transfer could be granted conditional on the level of the resource stock (T(S) with $T_S > 0$). Given the fact that the regime is corrupt, it can be assumed - based on case study evidence - that only a part of the international transfer reaches its intended target. In other words, suppose the government embezzles a fraction α of this aid. For simplification, if $\alpha < 1$, the rest of the transfer is supposedly destined for a payoff-neutral use, for instance to pay off a part of the country's foreign debt.[61]

$$(C_1^T)\ \underset{Q}{Max} \quad \int_0^\infty e^{-\delta t}[\pi(p,S,Q)-B(Q)+\beta[B(Q)+\alpha T(S)]+U(S)-P(S)]dt$$

subject to $\dot{S} = F(S) - Q - \bar{H}(S)$, where recall that $P(S) = \rho(S)C(L(S,w))$, and $P_S = \rho_S C + \rho C_L L_S$.

The truthful contribution and quota also solve:

$$(C_2^T)\ \underset{Q}{Max} \quad \int_0^\infty e^{-\delta t}[2\pi(p,S,Q)-2B(Q)+\beta[B(Q)+\alpha T(S)]+U(S)-P(S)]dt$$

subject to $\dot{S} = F(S) - Q - \bar{H}(S)$.

The solution to this optimization problem is given in the Appendix section (11) which provides the optimal exploitation condition in the presence of resource management - targeted international aid:

$$(F_S - \bar{H}_S) + \frac{\beta\pi_S + U_S + \alpha\beta T_S - P_S}{\beta\pi_H} = \delta. \qquad (1.11)$$

Again, the marginal stock effect is unambiguously increased by the transfer, since $T_S > 0$ and $\beta > 1$, and so the transfer attains its conservationist goal.

Comparing this to the quota set by the corrupt government without international aid (1.6) and calculating the comparative statics yield the following:

[60] A 2007 initiative titled 'Leaving Ecuador's Oil in the Ground,' seeks to attract international funding to avoid carbon emissions and save the Yasuni Rainforest where '[at] least two indigenous tribes, the Tagaeri and Taromenane, maintain their traditional lifestyles in voluntary isolation', according to the World Resources Institute. See http://www.wri.org/.

[61] This is assumed in order to simplify the calculation. The inclusion of the remainder $(1-\alpha)T$ in the government's utility function would not change the results qualitatively.

Proposition 4: *Conditional international aid leads to a higher equilibrium level of stock and the magnitude of the reduction in harvesting is proportional to the 'embezzlement' coefficient α (and can also increase in the corruption coefficient β).*

Proof: provided in the Appendix section (11).

The intuition for this result is simple. Aid directly decreases the attractiveness of resource exploitation for the government. The fact that the transfer is partly appropriated by the government means that the relative 'value of conservation' rises in the corrupt government's objective, and so the equilibrium stock level increases in the presence of aid conditional on the resource policy, with the increase being positively related to regulator corruption.[62]

It is straightforward to show that this result is not driven by particular assumptions related to the form of the international transfer. Alternatively, the transfer T can be designed as a function of the regulated harvesting: $T(Q)$ where $T_Q < 0$. The critical assumption is, again, that the international donors have some monitoring capabilities in place for the resource policies set by the government: the quota Q is either directly observable or can be inferred from the industry's financial statements. The government manages to embezzle a fraction α of the transfer and solves the following problem:[63]

$$(C_1^T)' \ \underset{Q}{Max} \quad \int_0^\infty e^{-\delta t}[\pi(p,S,Q) - B(Q) + \beta[B(Q) + \alpha T(Q)] + U(S) - P(S)]dt$$

subject to $\dot{S} = F(S) - Q - \bar{H}(S)$.

The truthful contribution and quota also solve:

$$(C_2^T)' \ \underset{Q}{Max} \quad \int_0^\infty e^{-\delta t}[2\pi(p,S,Q) - 2B(Q) + \beta[B(Q) + \alpha T(Q)] + U(S) - P(S)]dt$$

subject to $\dot{S} = F(S) - Q - \bar{H}(S)$ and the truthful resource exploitation policy rule satisfies the following relation, as the Appendix section (11) further details:

$$(F_S - \bar{H}_S) + \frac{\beta\pi_S + U_S - P_S}{\beta\pi_Q + \alpha\beta T_Q} = \delta,$$

where $T_Q < 0$ and the marginal stock effect is again increased by the presence of the conditional aid. As long as both trade sanctions and international

[62] Barbier and Schultz (1997) obtain a similar result in a setting where they consider habitat conversion (p. 161).

[63] The rest of the transfer has no further redistributive repercussions, as it is mandated to go towards a public good destination, e.g. re-paying the country's external debt.

aid increase the equilibrium level of the resource stock, they contribute to a decreased equilibrium likelihood of conflict.

1.3 Summary and Conclusions

Natural resources can be a powerful motivator of social and political change. The issue of resource-based civil conflicts is a growing topic in both political science and economic literatures, and it has so far been approached from various angles. This paper looks at the effect of official corruption on the exploitation of renewable resources and then on the likelihood for the emergence of conflict, as it attempts to derive testable implications. The study builds on classical political economy models like Grossman and Helpman (1994) and looks at a dynamic externality in the form of renewable resource harvesting and three economic actors: the opportunistic government, the resource corporations that are in a position to influence the harvesting quota by bribing the regulator, and the peasant harvesters that live off the resource.

For tractability reasons, the analysis focuses on the steady-state equilibrium. It is shown in a framework where conflict is not a factor, that the opportunistic government is less conservationist than an honest one. Resource depletion sanctioned by an opportunistic government on one hand increases locals' discontent and the government's appeasement or deterrence costs. On the other hand, in conjunction with the outside opportunities, depletion may weaken the peasant (and potential rebel) workforce. The shadow of conflict can be conservationist when the first effect dominates, by increasing the implicit political influence of the small harvesters. The probability of resource-based conflict may increase or decrease, according to the discontent effect and the migration effect, which in turn depend on the parameters of the system. International sanctions aimed at improving the domestic environmental performance and which result in decreasing firms' profits are shown to work under reasonable conditions, while the effectiveness of environmentally-targeted international aid may depend on corruption in a counter-intuitive way.

It is then argued that the relationship between governmental corruption, the environmental outcome, and the political outcome is complex. Moreover, without positing specific functional forms that put a dent in generality, this issue is primarily empirical. The main hypotheses put forth are that a higher population level and a lower income level increase the chances for violence and that while depletion increases the probability of conflict in 'not too depleted environments', the marginal effect of depletion on the likelihood of resource-based conflict may decrease in corruption. These implications are further explored in the following chapter.

APPENDIX:

(1). The current value Hamiltonian for the honest government's problem can be written as:

$\mathcal{H} = \pi(p, S, Q) + U(S) + \mu[F(S) - Q - \bar{H}(S)]$ and the first order conditions are the following:

$\frac{d\mathcal{H}}{dQ} = \pi_Q - \mu.$

Notice that for specific profit functions that are multiplicatively separable in Q and take the form $\Pi(p, S)Q$ this condition does not depend on the control variable, and so the solution is reached by taking the most rapid approach path (MRAP) as follows: if $\frac{d\mathcal{H}}{dQ} > 0$ by setting harvesting at the maximum level $Q = Q_{max}$, where Q_{max} is the exploitation resulting from employing the maximum effort available (bounded perhaps by the available industry labour force and/or technological parameters), while if $\frac{d\mathcal{H}}{dQ} < 0$ by setting harvesting at the minimum level $Q = Q_{min}$ (which can be zero or the break-even point for the firms). This is allowed until the shadow price of the resource μ respectively increases or decreases to equal the unit profit. The other optimality relations are derived from:

$\frac{d\mathcal{H}}{dS} = \delta\mu - \dot{\mu} = \pi_S + U_S + \mu(F_S - \bar{H}_S)$

$\frac{d\mathcal{H}}{d\mu} = \dot{S} = F(S) - H - \bar{H}(S).$

while the following transversality condition has to hold:

$\lim_{t\to\infty} \; e^{-\delta t}\mu(t)S(t) = 0.$

Imposing the conditions of zero-growth of the state and co-state variables in a steady-state equilibrium and assuming the transversality condition holds, we obtain:

$(F_S - \bar{H}_S) + \frac{\pi_S + U_S}{\pi_Q} = \delta.$

To determine the transitional path dynamics, take time-derivative of the first condition to obtain: $\dot{\mu} = \pi_{QQ}\dot{Q} + \pi_{QS}\dot{S}$ which can be substituted into the second condition as follows: $(\delta - F_S - \bar{H}_S)\pi_Q - \pi_{QQ}\dot{Q} - \pi_{QS}[F(S) - Q - \bar{H}(S)] = \pi_S + U_S$. The $\dot{H} = 0$ locus can then be determined as:

$H = \underbrace{\frac{\pi_S + U_S - (\delta - F_S - \bar{H}_S)\pi_Q}{\pi_{QS}}} + (F(S) - \bar{H}(S))$, where the sign of its slope $(\frac{dH}{dS}|_{\dot{H}=0})$ is ambiguous.

Notice that setting the numerator of the fraction to zero, which is our golden rule above, is equivalent to imposing the steady-state harvesting condition. Transitional harvesting is decreasing towards the steady-state value when the fraction (its numerator) is positive, and increasing when it is negative.

(2). The current value Hamiltonian of the corrupt government's problem can be written as:

$\mathcal{H} = \pi(p, S, Q) + (\beta - 1)B(Q) + U(S) + \mu[F(S) - Q - \bar{H}(S)]$.

Note, again, that the government is opportunistic for values of β above 1. According to the maximum principle, the first order conditions for an interior solution are given by:

$\frac{d\mathcal{H}}{dQ} = 0 = \pi_Q + (\beta - 1)B_Q - \mu$

$\frac{d\mathcal{H}}{dS} = \delta\mu - \dot{\mu} = \pi_S + U_S + \mu(F_S - \bar{H}_S)$

$\frac{d\mathcal{H}}{d\mu} = \dot{S} = F(S) - Q - \bar{H}(S)$, and we assume the transversality condition to hold.

Taking the time derivative in the first condition above yields: $\dot{\mu} = \pi_{QQ}\dot{Q} + (\beta - 1)B_{QQ}\dot{Q} + \pi_{QS}\dot{S}$ and plugging it into the second condition:

$$(\delta - F_S + \bar{H}_S)[\pi_Q + (\beta - 1)B_Q] - \pi_{QQ}\dot{Q} - (\beta - 1)B_{QQ}\dot{Q} - \pi_{QS}\dot{S} = \pi_S + U_S.$$

(3). The problem of maximizing the joint industry-government payoffs is solved in a very similar fashion:

Use current value Hamiltonian $\mathcal{H} = 2\pi(p, S, Q) + (\beta - 2)B(Q) + U(S) + \lambda[F(S) - H - \bar{H}(S)]$ to get first order conditions:

$\frac{d\mathcal{H}}{dQ} = 0 = 2\pi_Q + (\beta - 2)B_Q - \lambda$

$\frac{d\mathcal{H}}{dS} = \delta\lambda - \dot{\lambda} = \pi_S + U_S + \lambda(F_S - \bar{H}_S)$

$\frac{d\mathcal{H}}{d\lambda} = \dot{S} = F(S) - Q - \bar{H}(S)$.

Together these conditions imply:

$$(\delta - F_S + \bar{H}_S)[2\pi_Q + (\beta - 2)B_Q] - 2\pi_{QQ}\dot{Q} - (\beta - 2)B_{QQ}\dot{Q} - 2\pi_{QS}\dot{S} = 2\pi_S + U_S.$$

(4). (i) A higher discount rate δ means that in order for equation (1.6) to hold, the equilibrium stock of the resource will adjust to a lower level, corresponding to a higher net growth rate $F_S - \bar{H}_s$ and a lower marginal stock effect (MSE), both evaluated at the optimal stock level. A more impatient corrupt government will regulate harvesting so that the resource stock settles at a lower long-run level.

(ii) To show Lemma 3, assume we have two functions of the stock of the same resource $MSE_1(S)$ and $MSE_2(S)$, where $MSE_2(S) > MSE_1(S)$, $\forall S \in [0, K]$. This is then true, in particular, for $S = S_2^* : MSE_2(S_2) > MSE_1(S_2)$ $(*)$.

We also know that the following two relations governing optimal exploitation are verified at the optimum levels of stock S_1^* and S_2^*:

$F_S(S_1^*) + MSE_1(S_1^*) = \delta$ and

$F_S(S_2^*) + MSE_2(S_2^*) = \delta$, where the resource dynamics and the discount rate are common across the two problems. Assume, by contradiction, that

$S_2^* < S_1^*$. It follows that $F_S(S_1^* < F_S(S_2^*)$ and then for the above equations to hold concomitantly, we need $MSE_1(S_1^*) > MSE_2(S_2^*)$ $(**)$. Put together, the two starred relations imply that $MSE_1(S_1^*) > MSE_1(S_2^*)$, which further implies - since the functions representing the marginal stock effects under the different policy regimes are decreasing in the level of stock - that $S_2^* > S_1^*$, which is a contradiction.

(5). It is easy to see that $MSE^c_{n/c} < MSE^h_{n/c}$ (where the subscripts refer to 'no-conflict' and the superscripts to government corruption) iff $\frac{\beta\pi_S+U_S}{\beta\pi_H} < \frac{\pi_S+U_S}{\pi_H}$. This is true in all cases, given the assumption that $\beta > 1$.

Alternatively, differentiate (1.6) with respect to the corruption coefficient to obtain:

$$\beta^2\pi_Q^2(F_{SS} - \bar{H}_{SS})S_\beta + S_\beta[(\beta\pi_{SS} + U_{SS})\beta\pi_Q - (\beta\pi_S + u_S)\beta\pi_{QS}] + \\ \beta\pi_Q\pi_S - (\beta\pi_S + U_S)\pi_Q = 0,$$

which implies:

$$S_\beta = \frac{U_S\pi_Q}{\beta^2\pi_Q^2(F_{SS}-\bar{H}_{SS})+(\beta\pi_{SS}+U_{SS})\beta\pi_Q-(\beta\pi_S+u_S)\beta\pi_{QS}} < 0,$$

where the inequality derives from the concavity of functions F, π and u.

(6). The current value Hamiltonian for the government utility maximization problem when conflict is possible is:

$\mathcal{H} = \pi(p, S, Q) + (\beta - 1)B(Q) + U(S) - \rho(S)C(L(S, w)) + \mu[F(S) - H - \bar{H}(S)]$ and the first order conditions are:

$\frac{d\mathcal{H}}{dQ} = 0 \rightarrow \pi_Q + (\beta - 1)B_Q = \mu$

$\frac{d\mathcal{H}}{dS} = \delta\mu - \dot{\mu} = \pi_S + U_S - \rho_S C - \rho C_L L_S + \mu(F_S - \bar{H}_S)$

$\frac{d\mathcal{H}}{d\mu} = \dot{S} = F(S) - H - \overline{h}$.

Take derivative with respect to time in the first condition above and plug into the second to obtain:

$(\delta - F_S + \bar{H}_S)[\pi_Q + (\beta - 1)B_Q] - [\pi_{QQ} + (\beta - 1)B_{QQ}]\dot{Q} = \pi_S + U_S - \rho_S C - \rho C_L L_S$

In the steady state: $(\delta - F_S + \bar{H}_S)[\pi_Q + (\beta - 1)B_Q] = \pi_S + U_S - \rho_S C - \rho C_L L_S$ and this implies: $B_Q = \frac{1}{\beta-1}[\frac{\pi_S+U_S-\rho_S C-\rho C_L L_S}{\delta-F_S+\bar{H}_S} - \pi_Q]$.

Similarly, the joint industry-government surplus maximization yields in the steady-state:

$(\delta - F_S + \bar{H}_S)[2\pi_Q + (\beta - 2)B_Q] = 2\pi_S + U_S - \rho_S C - \rho C_L L_S$.

Plug in B_Q from above to get the steady state equilibrium policy rule for renewable resource exploitation when conflict is possible: $F_S - \bar{H}_S + \frac{\beta\pi_S+U_S-\rho_S C-\rho C_L L_S}{\beta\pi_H} = \delta$.

(7). Compare this to the case without conflict and with a corrupt government in (1.6). Notice that the marginal stock effect with conflict is larger than the marginal stock effect without conflict if $-\rho_S C - \rho C_L L_S > 0$ or if $\frac{-\rho_S}{\rho} > \frac{C_L L_S}{C}$. Given the expressions for ρ, C and their derivatives with respect to stock provided in the text, this becomes equivalent to $\ln \frac{\bar{q}S}{w}(\bar{q} - \frac{w}{S}) > \frac{w}{S} - \frac{w}{S^*} + \frac{w \ln \frac{\bar{q}S}{w}}{S} - \frac{w \ln \frac{\bar{q}S^*}{w}}{S^*}$, which is further equivalent to $\frac{(\frac{\bar{q}S}{w}-2)\ln \frac{\bar{q}S}{w} - 1}{S} > -\frac{\ln \frac{\bar{q}S^*}{w}+1}{S^*} = -\varepsilon \Leftrightarrow (\frac{\bar{q}}{w} \ln \frac{\bar{q}}{w} + \varepsilon)S + (\frac{\bar{q}S}{w} - 2)\ln S - 2\ln \frac{\bar{q}}{w} - 1 > 0$. Denoting by θ the coefficient of S and with ϕ the constant, the previous inequality can be written: $G(S) = \theta S + (\frac{\bar{q}S}{w} - 2) lnS - \phi > 0$.

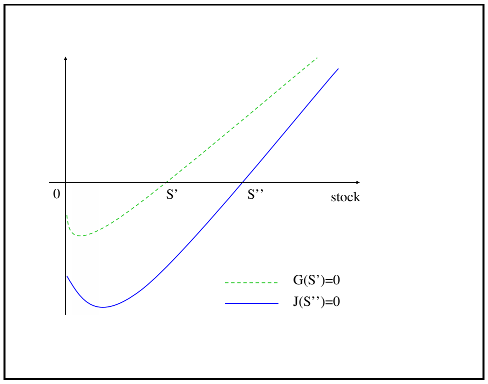
Function $M(S)$ is defined in the text based on equation (1.6) as being equal to $(\delta - F_S + \bar{H}_S)\beta\pi_Q - \beta\pi_S + U_S$. Substituting the given functional forms, it becomes:

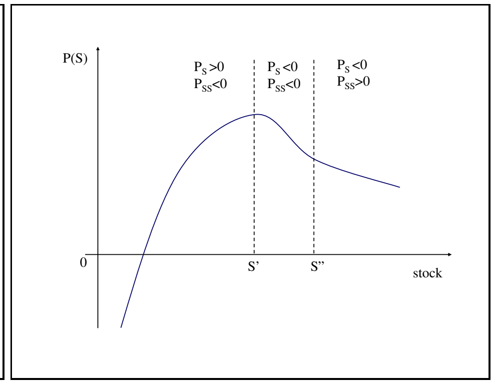
$M(S) = \frac{4pr}{K}S^4 + (\delta p - 2pr - \frac{5cr}{K})S^3 + c(3r - \delta)S^2 + \bar{h}(2pw - c\bar{q} - \frac{1}{\beta}\ln \frac{\bar{q}}{w})S - \frac{\bar{h}}{\beta}S \ln S - c\bar{h}w$.

(8). Differentiating (1.7) implicitly with respect to β yields: $(\pi_S + \beta\pi_{SS}S_\beta + U_{SS}S_\beta - \rho_{SS}CS_\beta - \rho_S C_L L_S S_\beta - \rho_S C_L L_S S_\beta - \rho C_L L_{SS} S_\beta)\beta\pi_H - (\beta\pi_S + u_S - \rho_S C - \rho C_L L_S)(\pi_H + \beta\pi_{HS}S_\beta) = -F_{SS}S_\beta\beta^2\pi_H^2$. This implies: $S_\beta = \frac{\pi_H(u_S - \rho_S C - \rho C_L L_S)}{(\beta\pi_{SS} + U_{SS} - \rho_{SS}C - 2\rho_S C_L L_S - \rho C_L L_{SS})\beta\pi_H + F_{SS}\beta^2\pi_H^2 - (\beta\pi_S + u_S - \rho_S C - \rho C_L L_S)\beta\pi_{HS}}$ is less than zero if $S > S'$ and $S > S''$, since under the first condition the numerator is positive as $P_S < 0$, while under the second, the denominator is negative, as $P_{SS} > 0$ (see below).

(9). $P(S) = \rho(S)C(L(S,w))$ and it was shown above that $P_S = \rho_S C + \rho C_L L_S < 0$ if and only if $S > S'$. Calculate the condition $P_{SS} = \rho_{SS}C + 2\rho_S C_L L_S + \rho C_L L_{SS} > 0$ by using the functional forms provided above as follows: $(2\ln \frac{\bar{q}S}{w} - 1)(\bar{q} - \frac{w}{S}) - \frac{2w}{S}\ln \frac{\bar{q}S}{w} - 2w(\frac{1}{S} - \frac{1}{S^*}) - 2w(\frac{\ln \frac{\bar{q}S}{w}}{S} - \frac{\ln \frac{\bar{q}S^*}{w}}{S^*}) > 0 \Leftrightarrow 2(\frac{\bar{q}S}{w} - 3)(\ln \frac{\bar{q}}{w} + \ln S) - 1 > -aS$, where $a = \frac{2}{S^*}(1 + \ln \frac{\bar{q}S^*}{w}) - \frac{\bar{q}}{w}$ which further yields $(\frac{2\bar{q}}{w}\ln \frac{\bar{q}}{w} + a)S + 2(\frac{\bar{q}S}{w} - 3)\ln S - (6\ln \frac{\bar{q}}{w} + 1) > 0$. Denoting with b the coefficient of S and with c the constant, this becomes: $J(S) = bS + 2(\frac{\bar{q}S}{w} - 3)\ln S - c > 0$. The analysis is now similar to the one in section (7) above, and the graphical solution points to the fact that $P_{SS} > 0$ if and only if $S > S''$, which is lower for higher $\bar{q}$ and lower w and S^*.

(10). We need the numerator of the fraction in (2.12) to be positive. The result holds for all profit functions for which the price derivative depends on the level the resource only via quantity, or $\pi_{pS} = Q_S$. Under this reasonable assumption, the result is general. To see this, notice that the numerator in (2.11) is positive if and only if $\frac{\partial \pi}{\partial S} + \frac{U_S}{\beta} - P_S > \frac{\pi_{Sp}}{\pi_{Qp}}\pi_Q$. For $S > S'$ (thus $P_S < 0$), a sufficient condition for this last inequality to hold is that $\frac{\pi_{Sp}}{\pi_{Qp}}\pi_Q < \frac{\partial \pi}{\partial S}$. When $\pi_{Sp} = \pi_{pS} = Q_S$ and $\pi_{Qp} = \pi_{pQ} = 1$ (e.g. $\pi = [p - c(S)]Q(S)$), this sufficient condition is equivalent to $Q_S\pi_H < \frac{\partial \pi}{\partial S}$. This is true, since $\frac{\partial \pi}{\partial S} =$





$\pi_S + \pi_Q Q_S$: the partial effect of S on profits is composed of a direct effect that works via lower costs, and another indirect effect that works through a higher steady state harvesting quota. The denominator of the fraction in (2.12) is negative when $S > S''$, thus $P_{SS} > 0$. The graph below plots the probability of conflict as a function of the resource stock, where $S' < S''$ and $\lim_{S\to 0} P(S) = -\infty$, which obtains since $\lim_{S\to 0}[\frac{\gamma}{U^*}(\bar{q} - \frac{w}{S})] = -\infty$ and upon application of the l'Hôpital rule, $\lim_{S\to 0} \Delta U = +\infty$.

(11). If the transfer is conditional on the stock level $(T(S), T_S > 0)$ and if a fraction α of it is embezzled by the corrupt regulator, the problem of maximizing the government's utility has the following Hamiltonian function:

$\mathcal{H} = \pi(p, S, Q) + (\beta - 1)B(Q) + \alpha\beta T(S) + U(S) - P(S) + \mu[F(S) - Q - \bar{H}(S)]$. and the first order conditions:

$\frac{d\mathcal{H}}{dQ} = 0 = \pi_Q + (\beta - 1)B_Q - \mu$

$\frac{d\mathcal{H}}{dS} = \delta\mu - \dot{\mu} = \pi_S + \alpha\beta T_S + U_S - P_S + \mu(F_S - \bar{H}_S)$

$\frac{d\mathcal{H}}{d\mu} = \dot{S} = F(S) - Q - \bar{H}(S)$.

Taking the time derivative in the first condition and substituting into the second yields:

$(\delta - F_S + \bar{H}_S)[\pi_Q + (\beta - 1)B_Q] - \pi_{QQ}\dot{Q} - (\beta - 1)B_{QQ}\dot{Q} = \pi_S + \alpha\beta T_S + U_S - P_S$.

In the steady-state this becomes:

$(\delta - F_S\bar{H}_S)[\pi_Q + (\beta - 1)B_Q] = \pi_S + \alpha\beta T_S + U_S - P_S$.

Similarly, solving the joint government-industry objective maximization (C_2^T) yields:

$(\delta - F_S + \bar{H}_S)[2\pi_Q + (\beta - 2)B_Q] = 2\pi_S + \alpha\beta T_S + U_S - P_S$.

Eliminating B_Q between the two equations above yields: $F_S - \bar{H}_S + \frac{\beta\pi_S + U_S - P_S + \alpha\beta T_S}{\beta\pi_Q} = \delta$.

To determine the effect of an increased marginal transfer in the form of an upward shift and/or rotation of the transfer function, express the above condition as:

$E = (F_S - \bar{H}_S - \delta)\beta\pi_Q + \beta\pi_S + U_S - P_S + (\alpha\beta+1)(\tau+T_S)$. In order to find the effect of T on the equilibrium stock level we added the 'shift parameter' τ. The effect of the transfer on the stock could then be determined as: $\frac{dS}{d\tau}$.[64]

Totally differentiate expression E to get: $\frac{dS}{d\tau} = -\frac{E_\tau}{E_S}$. Since $E_\tau = \alpha\beta > 0$, we get that $sign(\frac{dS}{d\tau}) = -sign(E_S)$, where $E_S = (F_{SS} - \bar{H}_{SS})\beta\pi_Q - (\delta - F_S + \bar{H}_S)\beta\pi_{QS} + \beta\pi_{SS} + U_{SS} + \alpha\beta T_{SS}$. From the concavity of functions F, π, u and T, and when $S > S''$ so that $P_S S > 0$, we get that expression E is decreasing in stock level and consequently $\frac{dS}{d\tau} > 0$: an upward shift in the transfer function increases the conservationist effect of conditional aid. This formally shows the first part of Proposition 4.

We have: $S_\tau = -\frac{\alpha\beta}{(F_{SS}-\bar{H}_{SS})\beta\pi_Q+(F_S-\bar{H}_S-\delta)\beta\pi_{QS}+\beta\pi_{SS}+U_{SS}-P_{SS}+\alpha\beta T_{SS}}$ and we can determine the marginal impacts of the corruption parameters on this conservationist effect. Thus,

$S_{\tau\alpha} = -\frac{\beta[(F_{SS}-\bar{H}_{SS})\beta\pi_Q+(F_S-\bar{H}_S-\delta)\beta\pi_{QS}+\beta\pi_{SS}+U_{SS}-P_{SS}+\alpha\beta T_{SS}]-\alpha\beta^2 T_{SS}}{[(F_{SS}-\bar{H}_{SS})\beta\pi_Q+(F_S-\bar{H}_S-\delta)\beta\pi_{QS}+\beta\pi_{SS}+U_{SS}-P_{SS}+\alpha\beta T_{SS}]^2}$ is positive, since the numerator is positive whenever $\beta[(F_{SS}-\bar{H}_{SS})\beta\pi_Q+(F_S-\bar{H}_S-\delta)\beta\pi_{QS}+\beta\pi_{SS}+U_{SS}-P_{SS}] < 0$ which holds under our assumptions on β and the primitive functions.

Moreover,

$S_{\tau\beta} = -\frac{\alpha[(F_{SS}-\bar{H}_{SS})\beta\pi_Q+(F_S-\bar{H}_S-\delta)\beta\pi_{QS}+\beta\pi_{SS}+U_{SS}-P_{SS}+\alpha\beta T_{SS}]}{[(F_{SS}-\bar{H}_{SS})\beta\pi_Q+(F_S-\bar{H}_S-\delta)\beta\pi_{QS}+\beta\pi_{SS}+U_{SS}-P_{SS}+\alpha\beta T_{SS}]^2} -$

$-\frac{[\alpha\beta[(F_{SS}-\bar{H}_{SS})\pi_Q+(F_S-\bar{H}_S-\delta)\pi_{QS}+\pi_{SS}+\alpha T_{SS}]}{[(F_{SS}-\bar{H}_{SS})\beta\pi_Q+(F_S-\bar{H}_S-\delta)\beta\pi_{QS}+\beta\pi_{SS}+U_{SS}-P_{SS}+\alpha\beta T_{SS}]^2}$ is also positive provided that $\alpha < \frac{(F_{SS}-\bar{H}_{SS})\pi_Q+(F_S-\bar{H}_S-\delta)\pi_{QS}+\pi_{SS}}{F_{SS}\pi_Q+(F_S-\delta)\pi_{QS}+\pi_{SS}+U_{SS}-P_{SS}}$.

If, instead, *the transfer is conditional on the harvest rate Q*, the Hamiltonian for problem (C_1^T)' in the text is:

$\mathcal{H} = \pi(p,S,Q) + (\beta-1)B(Q) + \alpha\beta T(Q) + U(S) - P(S) + \mu[F(S) - Q - \bar{H}(S).]$ and the first order conditions are:

$\frac{d\mathcal{H}}{dQ} = 0 = \pi_Q + (\beta-1)B_Q + \alpha\beta T_Q = \mu$

$\frac{d\mathcal{H}}{dS} = \delta\mu - \dot{\mu} = \pi_S + U_S - P_S + \mu(F_S - \bar{H}_S)$

$\frac{d\mathcal{H}}{d\mu} = \dot{S} = F(S) - Q - \overline{H}(S)$.

Taking the time derivative in the first condition and substituting into the second yields: $(\delta - F_S + \bar{H}_S)[\pi_Q + (\beta-1)B_Q + \alpha\beta T_Q] - \pi_{QQ}\dot{Q} - (\beta-1)B_{QQ}\dot{Q} - \alpha\beta T_{QQ}\dot{Q} = \pi_S + U_S - P_S$.

Program (C_2^T)' yields a similar expression in the form: $(\delta - F_S + \bar{H}_S)[2\pi_Q + (\beta-2)B_Q + \alpha\beta T_Q] - 2\pi_{QQ}\dot{Q} - (\beta-2)B_{QQ}\dot{Q} - \alpha\beta T_{QQ}\dot{Q} = 2\pi_S + U_S - P_S$.

[64] See e.g. Skonhoft and Solstad (1998) p. 30, who use a similar approach to determine comparative statics with respect to a function.

Imposing the steady-state conditions in both expressions above we get: $(\delta - F_S + \bar{H}_S)[\pi_Q + (\beta - 1)B_Q + \alpha\beta T_Q] = \pi_S + U_S - P_S$ and $(\delta - F_S + \bar{H}_S)[2\pi_Q + (\beta - 2)B_Q + \alpha\beta T_Q] = 2\pi_S + U_S - P_S$, which upon elimination of B_Q further yields: $F_S - \bar{H}_S + \frac{\beta\pi_S + U_S - P_S}{\beta\pi_Q + \alpha\beta T_Q} = \delta$. This policy rule implicitly gives the steady-state stock of the resource.

To compare this with the resource level in the absence of international aid, notice that the transfer is decreasing in harvesting quota Q or $T_Q < 0$ and then the marginal stock effect is higher with the transfer, ceteris paribus, representing a higher equilibrium stock.

Alternatively, we can think about a simple specific functional form for the transfer: $T(Q) = \theta - \phi Q$ with both coefficients positive, so that $T_Q = -\phi$. Plugging this into the expression for $MSE^T_{n/c}$ above yields a lower marginal stock effect than in the absence of the transfer.

Chapter 2

Revisiting the 'Grievance' Hypothesis: An Empirical Analysis of Environmental Depletion and Governance-Based Determinants of Civil Conflict

The study of civil conflicts is becoming an increasingly prominent topic in development economics. The majority of existent studies on the particular topic of resource-based conflicts are empirical. However, as emphasized by Blattman and Miguel in a recent paper, '...too little of the empirical literature is motivated by and clearly derived from formal theoretical models.'[65] The paper seeks to contribute to addressing this lack by employing an empirical specification based on the previously derived theoretical model of corruption-induced resource depletion and conflict.

The most cited articles in this empirical literature have been generated by the World Bank project on the Economics of Civil War, Crime and Violence. Analyzing 52 civil wars over a 40-year period (1960-1999), Collier and Hoeffler find an inverse U-shaped dependence of the likelihood of civil war on primary exports' share in GDP.[66] Subsequent studies have disputed the robustness of these findings, focusing mainly on the imprecision of the resource-dependence measure and of some other controls, or on the definition of conflict. Fearon and Laitin argue that civil conflicts are best explained by

[65] See Blattman and Miguel (JEL) 2008, p. 5.
[66] See Collier and Hoeffler (2004), p. 23.

the presence of conditions favourable for insurgency, such as overpopulation, poverty, instability, which lower the outside-options of recruits, and the existence of rough terrain, which decreases fighting costs for rebels. Many of the studies comprising the natural resources and civil conflict literature acknowledge the importance of the quality of state institutions. However, most fall short of providing a straightforward theoretical mechanism or empirical conclusions as to how this quality of governance matters.[67]

Following the theoretical model presented in the previous chapter, the stance adopted here is that in order to establish a salient link between the likelihood of domestic conflict and natural resources one must take into account the way specific resource exploitation is conducted. Specifically, excessive resource depletion has the potential to generate discontent. While the existence of natural resource rents constitutes a powerful motivation and may provide the financial means for various groups to contest the legitimacy of the incumbent government, it also allows the latter to buy social peace or tolerate conflict as a 'cost of doing business'. Embezzlement of public funds by the government via looting or bribery may increase the likelihood of civil unrest, yet it may also provide the necessary funds for the government to afford costly appeasement/deterrence measures.

Collier and Hoeffler's assumption in their 'Greed or Grievance' suite of papers was that in every society and at all points in time there are marginalized groups that have an incentive to overthrow the existing regime and that what distinguishes the peaceful and the violent cases is merely the existence of economic opportunity that favours insurgency. While this statement does have an intuitive appeal, it is unsatisfactory if one's interest lies in explaining precisely the circumstances that might lead to the disenfranchisement of certain groups in the society. When the focus is on uncovering the conditions sufficient for civil violence to become the preferred course of action by a certain party, a legitimate guiding question is: what caused it and what can be done to prevent it? In the case of poor, relatively resource-abundant countries, the attractiveness of looting is always a potential motivator, and the low outside options of recruits always a facilitator in the slide toward violence. However, the way the resource is exploited and the proceeds distributed in the wider society are bound to have an impact on both, while at the same time available governmental actions have the potential to 'buy' social peace.

[67] Humphreys (2005) argues that a strong state is able to reduce the destabilizing effects of natural resource rents, while Hegre (2003) suggests that a democracy is more prone to resource conflicts.

The only robust determinants of civil conflict over which there is consensus in the literature are the GDP per capita and the population level.[68] However, due to a widely-recognized under-theoretization of resource-conflicts, the choice of variables and specifications in many models has largely been ad-hoc. This chapter uses the theoretical model developed in the previous chapter to inform the empirical specification in an attempt to uncover a potential impact of resource policies and quality of governance on the prevalence of domestic conflict. The model of corruption and renewable resources provides theoretical justification for the investigation of the hypothesized empirical relationship between the likelihood for a particular country to be engaged in a civil war, basic economic indicators such as population and income levels, and the nature of its governance and natural resource policies. A panel data set is used to estimate a reduced-form empirical relationship based on the theoretical framework and thus to indirectly test the hypotheses advanced in the previous section.

The paper explores the relationship between the prevalence of civil resource - centered conflicts, the quality of governance and the management of natural resources on a large panel dataset including 120 countries over a 20 year period. The study further analyzes the discontent-based civil conflict hypothesis. While in the previous studies broad inequality and ethnic fragmentation variables were used to proxy for grievances, this channel is more closely explored here by employing data on resource depletion. It is shown that income, population level, the quality of governance, depletion and their interaction indeed appear as significant determinants of civil conflicts and have the hypothesized signs.

2.1 Empirical Implications From the Theory

The likelihood of resource-based conflict is positively related to the local population level, which is associated with the strength of the local harvesters in this model. In what follows, a country's population is used as a proxy, based on the assumption that the larger the population, the more likely it is to have such disenfranchised groups with a 'critical mass' membership, while the government's capabilities are more diluted. This is used for comparability with the literature. When rural population density is added to all regressions, it is also positive and significantly related to conflict incidence. However, this measure also exhibits a strong negative correlation with the

[68] See Hegre and Sambanis (2006), p. 509.

income measure. Conflict is negatively related to the level of outside opportunities, proxied for by income level and/or growth. While in the model the small harvesters attracted by better options simply exit the interest group, this is represented in the data by the notion that in a high income and/or high growth economy insurgency is less attractive as a career choice, even in the presence of legitimate grievances.

Resource depletion and corruption increase the likelihood of conflict when the parameters are such that the resource is not too scarce in equilibrium, which in the model occur as the outside opportunities are not very attractive for a high ability peasant population and the government's appeasement deterrence capabilities are low. An advanced degree of scarcity induces a weakening of the locals and a lowering of the probability that an open conflict would ensue. The variables used to proxy for resource depletion (net forest depletion and adjusted net savings) and governance quality (corruption and bureaucratic quality) are discussed in more detail below.

The interaction between the natural resource depletion and the quality of governance is important: corruption is less likely to cause violence in more depleted environments. While corruption fundamentally increases the probability of violence, in some circumstances, corruption may in fact be instrumental in allowing the government to appease the potential rebels weakened by migration.

The following presents the data, the empirical model and examines the validity of these findings in the sample.

2.2 Data

To assemble the panel data set information on natural resources, civil conflicts, governance and corruption, democracy and general macro-economic variables such as GDP level and growth or population is required. Several different sources are used for this purpose. A list of variables names, meaning and their sources is provided in the Appendix, and a brief introduction is provided in the following paragraphs.

The natural resource data comes from the World Bank's Adjusted Net Savings database, which in general provide measures of economics sustainability. The ANS project provides information since 1970 for a wide cross-section of countries on several indicators relevant to the main focus, such as: adjusted net savings, net forest depletion, mineral depletion, energy depletion, gross and net national savings, CO_2 pollution damage.[69] Following the

[69] Adjusted net savings are calculated as augmented standard national income account-

model, a narrow focus lies primarily in the renewable resources information, such as net forest depletion.[70] In a broad interpretation of the model, however, where the environment is viewed as a generic renewable resource, the data on adjusted net savings can also be informative. One important caveat of using the latter proxy variable should be noted here. While adjusted net savings data does bear the interpretation of a sustainability indicator, according to the World Bank,[71] and it includes environmental pollution and natural resource depletion as components, it is really a 'genuine' savings rate of the economy, and thus it measures more than just environmental/resource exploitation that we focus on here. For this reason, the results of the models including the broad adjusted net savings variable should be interpreted with caution.

Civil conflict data was obtained from the PRIO/Uppsala Armed Conflict Dataset[72] which - compared to previous efforts - extends the conflicts set by lowering the casualty threshold necessary for an episode of violence to qualify as a conflict from 1000, in the Correlates of War (C.O.W) project,[73] to 25-battle related deaths annually, while also keeping track of the intensity of the war. Thus, these data are much more inclusive, capturing significantly *more* than just the major civil conflicts worldwide, over the period 1946-2005. The operational definition of conflict used in the database is 'a contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25 battle-related deaths.'[74] The dataset also includes inter-state conflicts, however, in accordance with the stated interest, only the internal ones are kept.[75] While most of the previous empirical studies use the much more restrictive 1000 casualties per year threshold, the position expressed here is the following: whereas that body of work looks actually to identify the factors important in reaching that specific

ing figures deflated by the Gross National Income (GNI). Net forest depletion calculation is based of estimated depletion rents, 'calculated as the rent on that amount of extraction which exceeded the natural increment in wood volume.' More information is provided in the World Bank manual at: http://siteresources.worldbank.org/INTEEI/1105643-1115814965717/20486606/Savingsmanual2002.pdf

[70] Unfortunately, no similar data exist for fish or wildlife.

[71] See $http://go.worldbank.org/3AWKN2ZOY0$, accessed on April 2, 2009.

[72] See Gleditsch et al 2002.

[73] First started by Singer and Small (1972), at the University of Michigan, transferred to Penn State in 2001.

[74] See *UCDP/PRIO Armed Conflict Dataset Codebook*, p. 4.

[75] Categories 3 and 4, for 'internal armed conflict' and 'internationalized internal armed conflict', the latter group including civil wars that witness some form of external interference.

intensity of hostilities, this data allows to test more directly for determinants of civil conflict *emergence*. Moreover, this inclusiveness is important for the identification strategy, as explained a little further.

Reliable data about corruption and the general quality of governance are difficult to collect, due to the very nature of the phenomenon, premised on concealing its existence. Therefore all data sources available for a wide array of countries and time periods are not based on factual data, but rather on perceptions.[76] These perception-based corruption indicators are constructed with information from multiple sources, and so there are less chances of any systematic bias or measurement error. Among the most prominent in this category of sources, one can count the Transparency International's Corruption Perception Index started in 1995 with 41 countries gradually expanded to 158 in the present, the International Country Risk Guide which looks specifically at corruption in the political system, and the World Bank's Governance Indicators. The source for corruption data used here is the International Country Risk Guide (ICRG) score,[77] which refers specifically to corruption in the political system and to ties between business and politics. There are a number of governance indicators available, such as: Government Stability, Socioeconomic Conditions, Investment Profile, Military in Politics, Religion in Politics, Law and Order, Ethnic Tensions, Democratic Accountability, Bureaucracy Quality and Corruption, with the last two being the more relevant to the present focus. In particular, the measure of corruption refers to 'financial corruption in the form of demands for special payments and bribes...and suspiciously close ties between politics and business'.[78] As with all ICRG indicators, higher values of variables `corruption` and `bur.quality` signify better quality governance: *less* corruption and higher bureaucratic quality, respectively.

Additional controls incorporated in the data set come from World Bank's Development Indicators for variables such as: GDP levels and growth rates, population, agricultural products, food and ore exports, the general level of inequality, unemployment, foreign aid and others. Additionally, data from the POLITY IV project were used to account for the general level of

[76] Several studies analyze the distance between perception indicators and more factual-based measures of corruption. See Olken (2006) for a recent example, where a local measure of corruption in road-building in Indonesia is compared with corruption perceptions. Though interesting, this is not a significant problem in the present setting, where *perceived* mismanagement and embezzlement of public funds can equally generate revolt.

[77] International Country Risk Guide (Table 3B), C The PRS Group, Inc., 1984-Present. For more details see *http://www.prsgroup.com.*

[78] Citation from the ICRG codebook *A Business Guide to Political Risk for International Decisions*, p. 31.

Variable	*Obs.*	*Mean*	*Std. Dev.*	*Min.*	*Max.*
GDP growth	4238	3.287308	6.115611	-51.03086	106.2798
GDP per capita (PPP)	3906	8189.072	8563.14	466.1966	66702.59
Food exports	2798	25.23914	25.30327	.000238	99.11278
Fuel exports	2681	15.95988	25.86532	0	101.5603
Metal ore exports	2747	6.291353	11.86478	3.36e-06	88.81229
Gini coefficient	400	41.1678	10.80784	19.4	74.33
Aid	3267	8.251895	13.82001	-3.016838	242.2864
Aid per capita	3521	80.30627	215.12	-203.5889	2337.979
Population	4728	1.45e+08	5.95e+08	19700	6.44e+09
Rural population density	4013	555.3755	1121.809	0	13776.82
Subsidies and transfers	975	36.21356	21.67086	-.7346081	90.65208
Surface area	4536	3374.076	12867.36	.05	134000
Unemployment youth male	1178	16.37603	9.214946	1	69.2
Polity (democracy indicator)	3158	1.548132	7.255555	-10	10
Bureaucratic quality	2889	2.139171	1.20512	0	4
Control of corruption	2889	3.13674	1.382194	0	6.166667
Democratic accountability	2889	3.612924	1.646162	0	6
Conflict intensity	640	1.326563	.4693225	1	2
Peace before conflict	945	4.445503	9.4801	0	50
In conflict	945	.6772487	.4677761	0	1
ANS excluding PM10	2722	5.929805	13.77362	-108.63	42.36
ANS including PM10	1921	4.963566	13.8389	-109.65	41.67
ANS energy depletion	3582	4.217113	10.22142	0	79.12
ANS Gross National Savings	3292	18.27396	12.50415	-58.95	86.64
ANS mineral depletion	3596	.7258843	3.002218	0	56.95
ANS net forest depletion	3139	.5396974	1.559226	0	15.97
ANS Net National Savings	3289	7.919556	12.05643	-70.37	80.6

Figure 2.1: Summary statistics - selected variables

democracy in a country in the form of a special variable (`polity2`) designed specifically for time-series analyses.[79] The first table in Figure 2.1 details some important variables used in the analysis. Some correlations between important variables are presented in the second table in Figure 2.2.

Two relationships are particularly worth pointing out in this cross- correlations table. First, the ICRG indicators of corruption and bureaucratic quality, while positively correlated with the level of democracy in a country, are not related enough to actually instrument for one another, and can be justifiably inserted into the specification as independent regressors controlling for different aspects of a country's governance. Secondly, the correlations between the indicators of depletion and corruption over the sample

[79] For a thorough explanation of why a modification of the combined polity score is necessary, please refer to the original source: Marshall and Jaggers, *Polity IV Project: Data User's Manual* at www.cidcm.umd.edu/inscr/polity.

Variables	gdp	gwth	pop	pol	bqua	cor	anse	ansi	mid	nfd	end
Gdp per capita	1.00										
Gdp growth	-0.06	1.00									
Population	-0.06	0.14	1.00								
Polity	0.46	-0.07	-0.07	1.00							
Bureaucatic quality	0.78	-0.03	0.05	0.40	1.00						
Corruption control	0.62	-0.06	-0.09	0.41	0.64	1.00					
ANS excl. PM10	0.25	0.08	0.14	0.34	0.36	0.25	1.00				
ANS incl. PM10	0.26	0.08	0.13	0.35	0.37	0.25	0.99	1.00			
Mineral depletion	-0.16	-0.02	-0.02	-0.00	-0.10	-0.06	-0.07	-0.07	1.00		
Net forest depletion	-0.25	0.05	0.00	-0.17	-0.28	-0.18	-0.13	-0.12	-0.03	1.00	
Energy depletion	-0.07	0.09	-0.00	-0.43	-0.13	-0.23	-0.64	-0.65	-0.08	-0.12	1.00

Figure 2.2: Cross-correlations.

are also low, while bearing the 'right' signs.

2.3 Empirical Method and Results

Before looking at the main hypothesis related to the determinants of civil conflict, the following attempts to confirm - given the available data - another relationship established in the first chapter. The first proposition suggests a negative association between the quality of governance and the level of natural resource depletion. Indeed, as the table in Figure 2.3 illustrates, the lagged bureaucratic quality is negative and significantly correlated with the specific depletion indicator net forest depletion `nfd`, and the relationship is robust to the inclusion of additional controls, such as income level and growth, population or level of democracy. The same holds for the relationship between the generic environmental indicator `anse` and the control of corruption. When `inconflict` and `inconflict5` are added in columns 3 and 6, governance quality is not significant any longer, although it maintains the hypothesized sign. As a first piece of evidence for ruling out the possibility of reverse causation, our conflict indicator, `inconflict5`, which is a dummy that turns one when civil conflict occurs within five years from the observation year,[80] is not a significant determinant of depletion, while

[80] This time horizon is chosen for compatibility with the previous literature. A non-binary alternative is `intensitymax5`, which measures the maximum intensity of conflicts in a country during a period of 5 years from the observation year. However, the variability of this indicator is also limited, as it is zero for cases where conflict is absent, one for minor

entering with a positive sign for both environmental indicators. It appears that the anticipation of future conflict does not encourage curet-period over-exploitation in the sample. On the other hand, the lagged dummy for contemporaneous conflict `inconflict` is a significant determinant of net forest depletion, lowering exploitation and might be interpreted to correspond to our findings in Proposition 2 in the preceding theoretical part. The two conflict dummies are not significant determinants of either `nfd` or `anse` when entered alone, without the additional controls.[81]

Variables	*Dependent Variable: nfd*			*Dependent Variable: anse*		
	(1)OLS	*(2) OLS*	*(3) FE*	*(4) OLS*	*(5)OLS*	*(6)FE*
Bur.Quality (lag)	-0.072***	-0.070***	-0.007			
	(0.016)	(0.015)	(0.046)			
Corruption (lag)				0.733***	0.919***	1.057
				(0.211)	(0.219)	(0.653)
Gdp/capita (lag)		-0.013***	-0.032		0.242***	0.041
		(0.005)	(0.025)		(0.077)	(0.443)
Population (ln,lag)		0.143**	0.376		2.135***	-0.877
		(0.059)	(0.254)		(0.650)	(4.306)
Polity (lag)		0.005**	-0.007		0.085*	-0.108
		(0.003)	(0.007)		(0.047)	(0.125)
Inconflict (lag)			-0.178**			-0.622
			(0.072)			(1.276)
Inconflict5 (lag)			0.074			2.006
			(0.100)			(1.753)
Constant	0.580***	-0.006	-0.985	3.113**	-10.227***	2.561
	(0.124)	(0.305)	(1.343)	(1.257)	(3.466)	(23.889)
Observations	2317	2150	591	2114	2029	536
Groups	131	121	51	122	117	47

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 2.3: Depletion and governance quality

As for the determinants of civil conflict, the interest is in analyzing the relationship between the incidence of internal violence, resource depletion and quality of governance in a wide cross section of countries during 21 recent years. The only correlates of civil war that are consistently robust in the empirical literature are GDP per capita - displaying a negative relationship - and population levels - having a positive relationship - with both the onset and the incidence of domestic violence. The opportunity cost of participating in an armed insurgency is higher in a high average-income country,

conflict and two for large-scale civil war.

[81] Figure 2.6 in the Appendix presents some further robustness checks of these results.

while a larger population per se may increase the likelihood that one particular group may rebel against the government, in a territorial dispute or in a coup. Beyond these two factors, however, there is little agreement in the field. Still, Collier and Hoeffler's stark initial claims identifying rebellion with a 'quasi-criminal activity', based on their findings that dependence on primary commodity exports are an important determinant in the emergence of civil wars, while legitimate motives were dismissed, still seem to stimulate new research. While many papers concentrate on showing how by adopting different definitions, time periods or conflict data sets, their results cannot be replicated, few actually move forward and look for more convincing explanations.[82] One chief reason for this may have been that the body of theoretical literature to guide such empirical explorations is relatively slim.

Civil wars may have their origin in several different social phenomena. One potential source of resource-based conflicts is investigated here, namely discontent-driven rebellion. The following refines the investigation of a 'grievance' based motive for internal violence. Previously, the proxies used for grievances were broad and political-based: level of democracy and measures of ethnic and religious fractionalization.[83] Given the relatively large number of what appear to be resource-based conflicts out of the total civil conflicts, an additional way one can think about resource exploitation and the quality of the governance as factors leading a certain group to consider conflict was suggested above. Resource depletion data such as: net forest depletion, and adjusted net savings is used to proxy for the level of environmental exploitation/scarcity in a narrow and a broad sense, respectively, and governance indicators such as: corruption and bureaucracy quality to represent the quality of policy-making. Available additional controls include the Gini coefficient for income inequality, the percentage of unemployed young male as potential rebel recruits, the polity score on the democracy-autocracy scale for the political regime in the country.[84] The governance quality terms are also interacted with the depletion indicators.

The basic probit specification (without lags for simplicity) can be written

[82] Among the exceptions, one recent paper by Brunnschweiler and Bulte (2008) takes issue with the treatment of resource dependence (share of primary exports in GDP) as resource abundance, and the exogenous treatment of what may essentially be an endogenously determined variable. Alexeev and Conrad (2008) also caution against using bias-inducing export-related GDP shares.

[83] On the latter, some studies argue that it could be also interpreted as *preventing* conflict, since rebel recruitment is more difficult in more fragmented societies.

[84] Elbadawi and Sambanis (2002) find that the level of democracy and the level of ethnic fragmentation are significant determinants of civil conflict in their sample.

as follows:

$$\Phi^{-1}(Conflict_{it}) = \beta_0 + \beta_1 Income_{it} + \beta_2 Population_{it} + \beta_3 Gov.Quality_{it} + \\ + \beta_4 Depletion_{it} + \beta_5 (Gov.Quality * Depletion)_{it} + \beta_6 Democracy_{it} + \beta_7 Z_{it} + \\ + \nu_i + \epsilon_{it},$$

where Φ is the standard normal cumulative density function, income$_{it}$ is either the level of GDP per capita level (purchasing power parity) or GDP growth, Z includes other controls and i indexes the panels (countries), t is time measured in years, ν_i is the panel-specific, unobserved heterogeneity effect and ϵ_{it} is the error term.[85]

Income per capita has been widely used as a control in regressions of civil conflict. According to the model, a high income (level and/or growth) represents a high level of outside opportunities, having the effect of decreasing the numbers of potential rebels via migration, while population has an opposite (positive) influence on the incidence of civil conflict.[86] Also, expect the control of corruption to generally decrease the likelihood a domestic conflict ensues, while the depletion indicator should increase it. Recall from the first chapter that, for relatively depleted environments, the conflict-inducing effect of depletion decreases with corruption, which implies that the likelihood of conflict should be lower, the lower the ICRG corruption control score for these countries. Therefore, while the coefficient for corruption is expected to be negative, the interaction term between the corruption score and the depletion indicator is hypothesized to be positive. The estimation method is panel probit.[87] We explore random effects probit, panel probit, pooled probit, fixed effects panel logit, OLS and IV models. The results are summarized in the following tables.

[85] $\Phi(z) \equiv \int_{-\infty}^{z} (2\pi)^{-1/2} exp(-x^2/2)dx$. Alternatively, the specification could be expressed as: $Probability(Conflict_{it} = 1) = \Phi(\beta \cdot Z)$, where β and Z are, respectively, the vectors of coefficients and regressors.

[86] In an innovative paper that uses rainfall as an instrument for economic growth, Miguel et al. (2004) show that income growth is also a significant determinant of domestic conflict in Africa. Note that, although rainfall data exists for a wider cross-section of countries, this identification strategy is not available here, since rainfall instruments for economic growth only in a particular subset of agriculture-dependent economies where irrigation is lacking, such as Sub-Saharan Africa.

[87] The first table (in Fig. 2.4) presents a random effects probit model. Our choice in this exercise is somewhat conditioned by the software package capabilities. According to `Stata` Manual, 'There is no command for a conditional fixed effects model, as there does not exists a sufficient statistic allowing the fixed effects to be conditioned out of the likelihood'. Results from a panel fixed effects logit model are also reported in the appendix.

Since institutional variables are among the regressors, *reverse causality* is a potential problem. It could be argued that a high degree of corruption and resource exploitation might be due to the presence of conflict. In an unstable environment, the government bureaucrats may have short appointment horizons and might be attempting to make up for this 'shortcoming' by accepting side-payments in exchange for policy favours, and consequently the quality of governance decreases, exacerbating overexploitation. This potential problem has been explored first in Table 2.3 above, where conflict is shown not to be a salient determinant of environmental depletion. To further account for this possibility, the analysis takes advantage of the time structure of the data set and uses time lags for all right-hand-side variables. In addition, notice that there is another advantage, besides comprehensiveness, to adopting a lower death-threshold when defining conflicts which is worth pointing out in this context. It could be argued that attempts to rule out reverse causality by using one period-lagged regressors are not foolproof, since adverse consequences of the civil war can arise early, before the typical 1000-battle related deaths threshold is reached. The particular conflict database used here allows for an early detection of violence, so that the likelihood of anticipatory behavior from the regulator is reduced.

Alternatively, the results might be *spurious*: perhaps the relationship captures the fact that both sets of variables are trending, or perhaps there exists a factor that is not included in the regressions and that influences both the incidence of conflict and the governance quality variable. The latter source of spuriousness is investigated below by instrumenting for the quality of governance. The former is ruled out by including a time trend, and results do not change, except for slight increase in the significance of income growth, population and polity variables. The first set of results are presented in the table in Figure 2.4, where the two measures of governance quality (bureaucratic quality and control of corruption) and the two measures of environmental depletion (adjusted net savings and net forest depletion) are entered alternatively.

As hypothesized, the income level and growth have discouraging effects on conflicts: when good alternative options exist, participating in a rebellion is much less appealing. Also, the natural logarithm of population level has a positive and strongly significant effect, confirming the hypothesis. The interaction term between the quality of governance variable and the depletion indicator is significant. This statistical significance is interpreted to mean that the effect of resource depletion (forest in this case) on the incidence of civil conflicts is dependent on the governance variable (here control of corruption and bureaucratic quality), as hypothesized. Moreover, the rela-

Variables	*Dependent variable: inconflict5*					
	(1)PanelProbit	*(2)PanelProbit*	*(3)PanelProbit*	*(4)PanelProbit*	*(5)PanelProbit*	*(6)PanelProbit*
Gdp / cap (lag)	-0.040*	-0.041*	-0.017	0.015	-0.002	-0.041
	(0.024)	(0.025)	(0.027)	(0.034)	(0.028)	(0.025)
Gdp growth (lag)					-0.041***	-0.040***
					(0.014)	(0.012)
Population (ln,lag)	0.580***	0.579***	0.578***	0.685***	0.690***	0.609***
	(0.128)	(0.122)	(0.127)	(0.127)	(0.137)	(0.125)
Corruption (lag)	-0.361***	-0.409***				-0.419***
	(0.075)	(0.085)				(0.086)
Bur.Quality (lag)			-0.504***	-0.513***	-0.506***	
			(0.100)	(0.104)	(0.102)	
Adjusted Net Sav (lag)	0.038**			0.027**	0.027**	
	(0.015)			(0.012)	(0.011)	
Net forest depletion (lag)		-0.110	-0.036			-0.148
		(0.158)	(0.097)			(0.163)
Polity (lag)	-0.005	0.003	-0.003	-0.021	-0.019	0.004
	(0.014)	(0.014)	(0.013)	(0.015)	(0.014)	(0.014)
Corruption*anse (lag)	-0.012***					
	(0.004)					
Corruption*nfd (lag)		0.107*				0.124**
		(0.058)				(0.060)
Bur.Quality*anse (lag)				-0.017**	-0.016**	
				(0.007)	(0.007)	
Bur.Quality*nfd (lag)			0.183**			
			(0.076)			
Regime longevity				-0.005		
				(0.005)		
year	-0.110***	-0.112***	-0.104***	-0.099***	-0.101***	-0.113***
	(0.012)	(0.011)	(0.011)	(0.012)	(0.012)	(0.011)
Constant	215.459***	221.120***	204.569***	194.019***	196.823***	221.387***
	(23.161)	(22.325)	(21.953)	(24.608)	(23.220)	(22.470)
Observations	2128	2266	2266	2017	2127	2262
Groups	117	121	121	117	117	121

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 2.4: Civil conflict incidence

tionship between the prevalence of conflict and the governance variable also appears to exhibit the characteristics proposed in the theoretical section. While the (previous period) control of corruption and bureaucratic quality are negative and strongly significant, the interaction with the indicator of net forest depletion is positive and significant and with the adjusted net savings indicator (opposite of depletion) negative and significant. Calculating the marginal effects of the quality of governance and depletion variables confirm that the adjusted net savings and the control of corruption both decrease the likelihood of conflict in column 1, while the net forest depletion increases the likelihood of conflict and the bureaucratic quality decreases the likelihood of conflict in column 3.[88] These results provide confirmation

[88] The marginal effects on conflict evaluated at means are -0.0001(0.0004) for `anse` and

of the hypothesis derived in the theoretical section: while a poor governance quality is positively correlated with the incidence of civil conflicts, its effect is lower given a high level of environmental depletion.[89] In the fourth column, the effect of regime longevity has a negative sign, corresponding perhaps to a larger government capability to prevent conflict, yet it is not statistically significant. When the dependent variable is the binary variable `onset` instead, defined as a binary variable equal to one when there is a conflict in the current period conditional on previous period peace, the signs are generally maintained, but the significance is weakened, as one might expect by only considering contemporaneous conflicts.[90]

When running a panel logit, results are similar.[91] When employing a fixed effects panel logit instead,[92] many groups drop out (the sample is significantly reduced, due to the existence of all positive or negative outcomes within groups),[93] but the results do not change: the democracy level variable `polity` is no longer significant (since it varies little in time), but the corruption variable and the interaction term that constitutes the principal focus remain significant at 5% and have the hypothesized sign. The above regression was also ran in specifications featuring other dimensions of resource depletion. When using other indicators from the Adjusted Net Savings database, such as the Minerals Depletion, Energy Depletion, most of the results survive. This seems to suggest that resource depletion in general, is a significant determinant of conflict in the sample.[94] The paper also attempts to replicate some of the Collier and Hoeffler's findings using our data. However, none of the other primary commodity exports (fuel, food, minerals and ores) seem to have a significant influence on the incidence of civil war in the sample.[95]

Another potential source of endogeneity bias is the following. Perhaps

-0.031(0.0012) for `cor`, respectively 0.029(0.017) for `nfd` and -0.034(0.015) for `bqua`, where parentheses contain the associated standard errors.

[89] Notice the `anse` term is positive, however, when entered without the interaction term, it has the intuitive negative sign. When `nfd` is entered alone, it is a positive and significant determinant of conflict.

[90] See Figure 2.7 in the Appendix.

[91] See Table 2.6, the Appendix.

[92] Same table, columns 5,6.

[93] The panel fixed effects logit estimator is based on the probability of observing a positive outcome in the panel. Consequently, groups with all-positive outcomes have a conditional probability of being observed equal to one, and so are uninformative. See Gould, W. 1999. 'Within-group collinearity in conditional logistic regression.' In `Stata` FAQs. College Station, TX: Stata Corporation.

[94] See the Appendix, Table 8(5.4).

[95] See the Appendix, Tables in Figures 2.11 and 2.13.

some of the right-hand side variables are jointly determined: higher quality governance, or institutions may be the result of high levels of income per capita. This is the issue to which the analysis turns next.[96] Studying the role of institutions is difficult, given their plausible endogeneity to almost any conceivable model specification. Good instrumental variables are not easily available, and the practice has been to rely on the few ones coming mostly from the cross-country development literature. La Porta et al (1998, 1999) establish that the *legal origin* of the country is a salient determinant of the legal protection of investors and thus of economic development.[97] Acemoglu, Johnson and Robinson (2001) show that *settlers mortality*, available for 64 countries, is a good indicator for the type of institutions created by Europeans in the colonies, especially with regards to property rights protection. Bockstette, Chanda and Putterman (2002) present data on the *antiquity of the state* and argue for its usefulness as an instrument for the quality of institutions, if one is ready to accept a long-run learning-by-doing process in governance. While the strength of property rights is, undeniably, crucial for development, it is less of an issue in view of the theoretical framework, where we assume property rights are reasonably enforced. In the first stage data on state antiquity and legal origin is used, which are the more reasonable instruments for the quality of institutions in the sense used here, while also implying the smallest restriction of the sample of countries.

An instrumental variable approach is implemented in an IV-2SLS framework, which is preferable to a panel probit in the presence of endogeneity bias. This approach was previously followed in Miguel et al (2004).[98] Moreover, the OLS results can be given an easier interpretation. In the first stage regress the quality of governance indicators on the instruments and additional controls. The antiquity of the state (`statehist05`) and the legal origin (`legor`) indeed emerge as preferred instruments and their quality is better for the case of bureaucratic quality. Then run the IV regression of conflict incidence on the instrumented endogenous and hypothesized exogenous regressors and the results are presented in the table in Figure 2.5. The

[96] The quality of institutions has an overwhelming impact on the process of economic development, taking precedence over classical factors such as geography and trade, as shown in Rodrik, Subramanian, and Trebbi (2002). Presumably, they also are an important ingredient in the prevalence for domestic violence in society.

[97] The categories are British, French, Scandinavian, German and Socialist origin of the legal system. See La Porta et al.(1999).

[98] See also Wooldridge (2002). Miguel et al (2004) argue that the Rivers and Vuong (1998) two-stage conditional maximum likelihood estimator method designed for cross-sectional analysis 'requires strong specification assumptions' to be translatable to panel data (p. 738). The same idea is expressed in Elbadawi and Sambanis (2002), p. 327.

first column is the random effects panel probit model, the second a pooled probit. First, notice that the results obtained here are very similar. Secondly, most of the results that were previously emphasized survive in the regressions where the quality of governance is instrumented for: income is negative and significant, population is positive and significant, the quality of governance is negative and significant and so is the interaction between corruption control and adjusted net savings, although the interaction effect between bureaucratic quality and net forest depletion is no longer significant. Calculating the marginal effects of depletion and of quality of governance on the likelihood of civil conflict confirms again the hypotheses.[99]

Variables	*Dependent variable: inconflict5*					
	(1)Panel Probit	*(2) Probit*	*(3) Panel OLS*	*(4)IV*	*(5)Panel OLS*	*(6)IV*
Gdp growth	-0.025	-0.010	-0.003	-0.003	-0.006	-0.004
	(0.010)**	(0.005)*	(0.001)***	(0.001)**	(0.001)***	(0.002)
Population (ln,lag)	0.574	0.303	0.056	0.060	0.072	0.076
	(0.129)***	(0.023)***	(0.019)***	(0.018)***	(0.019)***	(0.032)**
Bur. Quality (lag)	-0.538	-0.368	-0.045	-0.071		
	(0.097)***	(0.033)***	(0.010)***	(0.039)*		
Corruption ctrl (lag)					-0.043	0.212
					(0.008)***	(0.174)
Net forest deplet. (lag)	-0.033	0.118	-0.006	-0.081		
	(0.098)	(0.046)**	(0.013)	(0.121)		
Adjusted Net Sav (lag)					0.003	0.064
					(0.002)*	(0.031)**
Bur. Quality*nfd (lag)	0.193	0.061	0.016	0.117		
	(0.077)**	(0.034)*	(0.007)**	(0.140)		
Corruption*anse (lag)					-0.001	-0.022
					(0.000)*	(0.011)**
Polity (lag)	-0.005	0.003	-0.005	-0.005	-0.004	-0.014
	(0.014)	(0.005)	(0.002)***	(0.002)**	(0.002)**	(0.008)*
Year	-0.105	-0.044	-0.009	-0.010	-0.012	-0.009
	(0.011)***	(0.005)***	(0.001)***	(0.001)***	(0.001)***	(0.005)*
Constant	205.507	86.160	18.705	19.845	23.447	16.980
	(21.896)***	(10.782)***	(2.068)***	(2.495)***	(2.237)***	(10.777)
Observations	2289	2289	2289	2160	2129	2024
Groups	124	124	124	116	117	111

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 2.5: Instrumental variable approach

In addition to being correlated with the endogenous variable - here the

[99] The marginal effect (and standard errors) of net forest depletion (`nfd`) in column 3 is 0.01(0.005) and the marginal effect of bureaucratic quality (`bqua`) is -0.015(0.003), while in column 5 the marginal effect of adjusted net savings (`anse`) is not significant 0.0001(0.0003), and the marginal effect of corruption control (`cor`) is -0.018(0.003). The signs of the marginal effects are generally preserved but significance is lost in the IV regressions in columns 4 and 6.

quality of governance - valid instruments have to also satisfy the exclusion restriction, i.e. they have to not be significant determinants of conflicts on their own. While this is plausible for the antiquity of the state, which likely does not have an impact on civil conflicts directly or through the other regressors than the one it instruments for, legal origin may determine the economic regressors. However, when only state antiquity is used as an instrument, the results do not change, apart from some decreases in the level of significance.[100]

In the admittedly simplistic theoretical model which was used here to inform the empirical specification, only resource policy can lead to conflict. For this reason the empirical analysis needs to control for other possible explanations. Many empirical investigations of civil conflicts include indicators of society fractionalization, be it ethnic, religious or linguistic. Our principal results are robust to controlling for the degree of heterogeneity in the population, although ethnic and linguistic fractionalization are positively correlated with the incidence of conflicts.

Artificially drawn post-colonial borders are thought to favour ethnic and territorial disputes, especially in Africa. Consequently, the database was updated with three measures of fractionalization taken from Alesina et al.(2003), referring to ethnic, language and religious dimensions. This is the most comprehensive source available and the three indices range from zero (perfect homogeneity) to one (perfect heterogeneity or fractionalization) are calculated as:

$$frac_j = 1 - \sum_{i=1}^{n} s_{ij}^2$$

where s_{ij} is the share of group i in country j.[101] Fractionalization is interpreted as the probability that two randomly chosen individuals belong to different ethnic, linguistic or religious group. Note that these are time-invariant measures[102] and therefore justify the use of the random effects probit model. As Elbadawi and Sambanis note, a fixed effects specification would create multicollinearity between the fixed individually-specific error-

[100] These results are also reported in the Appendix.

[101] i.e. Fractionalization equals 1 minus the respective group Herfindahl concentration index. See Alesina et al. (2003), p. 159.

[102] Although there is some evidence that these fractionalization measures are in principle endogenous in the long-run, due to diverse factors such as: differences in fertility rates across groups, migration, mixing, definitional changes and identity/affiliation shifts, they are shown to be very stable in a time frame of up to 30 years. See Alesina et al. (2003), p. 161.

component and the time invariant regressor.[103] Results are presented in Figure 2.6.

Figure 2.6: Civil conflict incidence and measures of fractionalization

Variables	*Dependent variable: inconflict5*				
	(1)PanelProbit	*(2)PanelProbit*	*(3)PanelProbit*	*(4)PanelProbit*	*(5)PanelProbit*
Gdp / cap (lag)	0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)*	(0.000)	(0.000)	(0.000)
Population (ln,lag)	0.628	0.579	0.668	0.561	0.573
	(0.142)***	(0.122)***	(0.135)***	(0.128)***	(0.130)***
Corruption (lag)	-0.360	-0.409	-0.416	-0.365	-0.407
	(0.087)***	(0.085)***	(0.085)***	(0.086)***	(0.085)***
nfd (lag)	-0.112	-0.110	-0.141	-0.118	-0.094
	(0.178)	(0.158)	(0.167)	(0.178)	(0.157)
Corruption *nfd (lag)	0.091	0.107	0.105	0.093	0.107
	(0.059)	(0.058)*	(0.058)*	(0.059)	(0.058)*
Polity (lag)	0.015	0.003	0.008	0.013	0.001
	(0.015)	(0.014)	(0.014)	(0.015)	(0.014)
year	-0.119	-0.112	-0.116	-0.118	-0.112
	(0.012)***	(0.011)***	(0.012)***	(0.012)***	(0.011)***
Ethnic fractionalization	1.732		2.064		
	(0.957)*		(0.670)***		
Language fractionalization	2.438			2.540	
	(0.803)***			(0.699)***	
Religion fractionalization	-2.083				-0.919
	(0.894)**				(0.842)
Constant	233.219	221.120	226.425	230.353	220.751
	(24.349)***	(22.325)***	(23.131)***	(23.933)***	(22.289)***
Observations	2210	2266	2251	2225	2266
Groups	118	121	120	119	121

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

The second column in the table in Figure 2.6 contains the general panel probit specification including lagged regressors and a time trend, columns three to five add -in turn - measures of ethnic fractionalization, language fractionalization and religious fractionalization, respectively, while column one includes all three dimensions. First, it can be seen that the relationships of interest to us remain significant in all columns[104] and change little in magnitude when the degree of fragmentation in the society is controlled for. Second, the measures of ethnic and linguistic fractionalization in a society have a positive influence on the likelihood of conflict:[105] as hypothesized,

[103] See Elbadawi and Sambanis (2002), p. 313.
[104] Though the level of significance of the interaction term drops to 5% in the first and fourth columns.
[105] This result confirms the findings of Elbadawi and Sambanis (2002), Hodler (2006).

some conflicts indeed seem to have roots in ethnic divisions. Third, religious fractionalization indicator has the opposite sign but is not statistically significant. This result is consistent with other studies in the literature and is usually explained by the fact that religious affiliation is 'more endogenous' than the other measures, as it is relatively easy to hide or change under an intolerant regime.[106]

Additional robustness checks are also reported in the Appendix.

2.4 Conclusion

The chapter analyzes empirically the importance of corruption and other indicators of governance quality in conjunction with the level of depletion of natural resources, as factors explaining the incidence of civil conflict. A panel data set containing a large cross section of countries during 20 recent years is used to show that corruption and depletion and their interaction appear, indeed, to significantly influence the chance for civil violence, lending support to the 'grievance' motive of conflict. This seems to suggest that it is not inconceivable, at least in some cases, that economic policy grievances are more than mere justifications used by rebels to mask their real objectives. In contrast to the appropriation channel which offers little in terms of policy advice, the resource policy mechanism yields the following policy prescription: a more inclusive resource policy in conjunction with better overall economic conditions are likely to decrease civil conflict incidence. The implicit uniformizing nature of an analysis like the one above prevents one to draw sharper conclusions. Case studies can be useful for more in-depth analysis of any particular instance of conflict, given the multitude of factors, their interactions and the incentives for misrepresentation of their true nature that concur and may lead to eruption of violence. Notice, however, that little in the analysis above applies strictly to resource-rich countries, unlike the empirical studies premised on the 'greed' assumption. Frustration with almost any type of government policy could potentially be accommodated in a similar framework.

Given the explicit modeling choices made in both the theoretical and the empirical sections, the interpretation proposed here does not claim to be a universal explanation of civil conflict. Nor is the empirical exercise solid

The latter paper's result that fractionalization is linked to the *perpetuation* of resource-related violence is driven by the assumption that the number of rival groups in the society is inversely proportional to property rights enforcement, and thus the productivity in legitimate economic activities.

[106] e.g. Alesina et al.(2003), p. 167.

proof that civil conflict is *caused* by resource depletion grievances when the policy channel is by assumption unavailable or insufficient to achieve a political balance in society. Rather, this is an attempt to, on one hand, suggest that economic analyses of conflict do not have to be premised on a priori dismissing legitimate causes but can accommodate them, and on the other hand, to point at the fragility of what still constitutes 'conventional wisdom' in the empirical studies of civil conflict.

APPENDIX:

Some of the most important variables in the dataset are detailed in the following table, which also lists their respective sources:[107]

Variable	Explanation	Source
intensity	Intensity of conflict in given year: 1-minor,2-war	UCDP-PRIO
c_onset2	Dummy turns 1 when a conflict breaks out in given year	based on UCDP-PRIO
inconflict	Dummy turns 1 when a conflict is ongoing in given year	based on UCDP-PRIO
inconflict5	Dummy turns 1 if conflict in the next 5 years	based on UCDP-PRIO
intensitymax5	Maximum intensity of conflict in the next 5 years	based on UCDP-PRIO
peacebefore	Number of years of continuous peace before given year	based on UCDP-PRIO
fuel_exp	Fuel exports (% of merchandise exports)	W.D.I.
pop	Population (deflated)	W.D.I.
gdp_cap	GDP per capita (deflated)	W.D.I.
gdp_growth	GDP growth (annual %)	W.D.I.
gini	Gini index	W.D.I.
unempl_ym	Unemployment, youth male (%)	W.D.I.
food_exp	Food exports (% of merchandise exp.)	W.D.I.
fuel_exp	Fuel exports (% of merchandise exp.)	W.D.I.
metalore_exp	Ores and metals exports (% of merchandise exp.)	W.D.I.
polity2	Revised combined polity score	POLITY IV project
ans_e	Adjusted Net Savings (PM10 excl.)	A.N.S.
ans_end	Energy Depletion	A.N.S.
ans_i	Adjusted Net Savings (PM10 incl.)	A.N.S.
ans_mid	Minerals Depletion	A.N.S.
ans_nfd	Net Forest Depletion	A.N.S.
cor	Corruption	PRS-ICRG
bqua	Bureaucratic Quality	PRS-ICRG

Table 2.3 in the text explores the empirical relationship between the quality of governance and the level of environmental depletion in a country. The table in Figure 2.6 below shows the same relationships hold when the governance quality `bqua` is combined with the environmental indicator `anse`, while the same is not true for the control of corruption indicator `cor`

[107] The following abbreviations have been used: UCDP-PRIO= Uppsala Conflict Data Project-International Peace Research Institute Oslo, W.D.I= World Development Indicators (World Bank, 2006), ANS database = Adjusted Net Savings Indicators (World Bank, 2006), PRS-ICRG = International Country Risk Guide from the Political Risk Services.

when used as a determinant for `nfd`. This can be tentatively interpreted as suggesting that corruption control has more systemic implications and is linked to higher level decisions, while bureaucratic quality may affect all levels of environmental decision-making.

Figure 2.7: Depletion and governance quality (`bqua` and `anse`, `cor` and `nfd`)

Variables	*Dependent Variable: anse*			*Dependent Variable: nfd*		
	(1)OLS	*(2) OLS*	*(3) FE*	*(4) OLS*	*(5)OLS*	*(6)FE*
Bur.Quality (lag)	1.689***	1.499***	2.502***			
	(0.277)	(0.292)	(0.798)			
Corruption (lag)				0.029**	0.013	0.119***
				(0.012)	(0.012)	(0.037)
Gdp/capita (lag)		0.116	-0.201		-0.015***	-0.013
		(0.078)	(0.426)		(0.005)	(0.025)
Population (ln,lag)		1.758***	-5.631		0.148**	0.404*
		(0.629)	(4.496)		(0.060)	(0.237)
Polity (lag)		0.096**	-0.076		0.004*	-0.010
		(0.046)	(0.124)		(0.003)	(0.007)
Inconflict (lag)			-0.548			-0.154**
			(1.265)			(0.071)
Inconflict5 (lag)			2.758			0.101
			(1.763)			(0.098)
Constant	1.768	-7.705**	28.855	0.331***	-0.206	-1.597
	(1.194)	(3.237)	(24.304)	(0.127)	(0.317)	(1.290)
Observations	2114	2029	536	2317	2150	591
Groups	122	117	47	131	121	51

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Another factor that appears to play a role in some of the existing empirical studies of civil conflict is the previous history of violence. We added the `peacebefore` variable, that measures the number of years at peace (since 1946) before the observation year. As it can be seen in Figure 2.13 (column 4), `peacebefore` is negative and strongly significant in a specification that has `inconflict5` as a dependent variable, while none of the other regressors, except for population and level of democracy, are significant any longer, although they keep the hypothesized signs. While this is a discouraging result, showing that violence breeds violence, it is also difficult to interpret, since the period of peace before the observation year is jointly determined with all the other regressors.

Figure 2.8: Civil conflict onset

Variables	*Dependent variable: conflict onset*					
	(1)PanelProbit	*(2)PanelProbit*	*(3)PanelProbit*	*(4)PanelProbit*	*(5)PanelProbit*	*(6)PanelProbit*
Gdp / cap (lag)	-0.014	-0.018	-0.015	-0.002	-0.002	-0.018
	(0.015)	(0.016)	(0.017)	(0.017)	(0.017)	(0.015)
Population (ln,lag)	0.182	0.145	0.157	0.207	0.207	0.146
	(0.066)***	(0.064)**	(0.063)**	(0.067)***	(0.068)***	(0.064)**
Corruption (lag)	-0.058	-0.100				-0.100
	(0.084)	(0.089)				(0.089)
anse (lag)	-0.003			-0.008	-0.008	
	(0.014)			(0.011)	(0.011)	
Corruption*anse (lag)	-0.004					
	(0.005)					
Polity (lag)	0.010	0.012	0.011	0.011	0.010	0.012
	(0.015)	(0.015)	(0.014)	(0.014)	(0.014)	(0.015)
year	0.013	0.012	0.014	0.015	0.015	0.012
	(0.014)	(0.013)	(0.012)	(0.013)	(0.013)	(0.013)
Net forest depletion (lag)		-0.149	0.078			-0.152
		(0.162)	(0.067)			(0.161)
Corruption*nfd (lag)		0.099				0.100
		(0.069)				(0.068)
Bur. Quality (lag)			-0.123	-0.167	-0.166	
			(0.110)	(0.113)	(0.113)	
Gdp growth (lag)					-0.001	-0.007
					(0.017)	(0.015)
Constant	-28.696	-25.879	-30.786	-32.643	-32.882	-27.021
	(27.293)	(26.579)	(24.866)	(25.972)	(26.245)	(26.725)
Bur. Quality*anse (lag)				-0.004	-0.004	
				(0.007)	(0.007)	
Bur. Quality*nfd (lag)			-0.020			
			(0.064)			
Observations	2128	2266	2266	2128	2127	2262
Groups	117	121	121	117	117	121

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 2.9: Robustness checks: different models

Variables	*Dependent variable: inconflict5*					
	(1)PanelProbit	*(2)PanelProbit,pa*	*(3)Panel gee*	*(4)PanelLogit*	*(5)PanelLogit, fe*	*(6) PanelLogit, fe*
Gdp growth (lag)	-0.029	-0.007	-0.003	-0.042	-0.070	
	(2.98)*	(1.80)***	(2.92)*	(2.82)*	(3.21)*	
Population (ln,lag)	0.539	0.202	0.057	0.889	2.005	12.910
	(4.23)*	(3.08)*	(2.93)*	(4.79)*	(0.90)	(3.85)*
Corruption (lag)	-0.444	-0.153	-0.044	-0.763	-0.607	-0.569
	(5.20)*	(5.27)*	(5.19)*	(5.41)*	(3.62)*	(3.27)*
Net Forest Depletion (lag)	-0.130	0.010	0.005	-0.219	-0.825	-0.845
	(0.81)	(0.13)	(0.22)	(0.82)	(2.04)**	(2.14)**
Corruption*nfd	0.133	0.018	0.003	0.232	0.195	0.238
	(2.23)**	(0.72)	(0.40)	(2.39)**	(1.82)***	(2.26)**
Polity (lag)	0.000	-0.007	-0.003	-0.004	0.029	0.032
	(0.02)	(1.27)	(1.94)***	(0.19)	(1.05)	(1.14)
Year	-0.114	-0.042	-0.012	-0.191	-0.227	-0.526
	(10.17)*	(10.18)*	(10.41)*	(10.09)*	(4.46)*	(5.98)*
Gdp/capita (lag)						0.001
						(4.53)*
Constant	225.016	81.715	23.422	375.984		
	(10.07)*	(10.18)*	(10.56)*	(9.98)*		
Observations	2289	2289	2289	2289	733	735
Groups	124	124	124	124	36	36

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 2.10: Robustness checks: different depletion indicators

Variables	*Dependent variable: inconflict5*					
	(1)*PanelProbit*	(2)*PanelProbit*	(3)*PanelProbit*	(4)*PanelProbit*	(5)*PanelProbit*	(6)*PanelProbit*
Gdp/capita (lag)	0.021	-0.041	-0.055	-0.045	-0.017	-0.007
	(0.026)	(0.025)*	(0.025)**	(0.024)*	(0.027)	(0.027)
Population (ln,lag)	0.596	0.579	0.544	0.570	0.578	0.597
	(0.131)***	(0.122)***	(0.126)***	(0.120)***	(0.127)***	(0.117)***
Corruption (lag)	-0.442	-0.409	-0.353	-0.442		
	(0.111)***	(0.085)***	(0.079)***	(0.077)***		
Bur.Quality (lag)	-0.606				-0.504	-0.578
	(0.135)***				(0.100)***	(0.098)***
Net Forest Dep. (lag)	-0.451	-0.110			-0.036	
	(0.167)***	(0.158)			(0.097)	
Energy depl. (lag)	-0.026		-0.017			
	(0.021)		(0.019)			
Mineral depl. (lag)	-0.557			-0.345		-0.372
	(0.109)***			(0.093)***		(0.067)***
Corruption*nfd (lag)	0.147	0.107				
	(0.060)**	(0.058)*				
Bur.Quality*nfd (lag)	0.220				0.183	
	(0.081)***				(0.076)**	
Corruption*end (lag)	0.005		0.004			
	(0.007)		(0.006)			
Bur.Quality*end (lag)	0.006					
	(0.008)					
Corruption*mid (lag)	0.076			0.122		
	(0.036)**			(0.031)***		
Bur.Quality*mid (lag)	0.214					0.234
	(0.043)***					(0.038)***
Polity (lag)	-0.014	0.003	0.006	0.000	-0.003	-0.016
	(0.014)	(0.014)	(0.014)	(0.014)	(0.013)	(0.014)
year	-0.115	-0.112	-0.108	-0.111	-0.104	-0.104
	(0.012)***	(0.011)***	(0.011)***	(0.011)***	(0.011)***	(0.011)***
Constant	227.255	221.120	212.205	218.803	204.569	203.703
	(24.078)***	(22.325)***	(22.230)***	(22.838)***	(21.953)***	(22.496)***
Observations	2266	2266	2296	2296	2266	2296
Groups	121	121	122	122	121	122

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 2.11: Robustness checks: additional controls 1

Variables	*Dependent variable: inconflict5*					
	(1)*PanelProbit*	(2)*PanelProbit*	(3)*PanelProbit*	(4)*PanelProbit*	(5)*PanelProbit*	(6)*PanelProbit*
Gdp /capita (lag)	-0.000	-0.000	-0.000	0.000	0.000	0.000
	(0.18)	(1.02)	(2.18)**	(1.97)**	(2.24)**	(1.98)**
Population (ln,lag)	0.726	0.635	0.612	0.938	0.964	0.829
	(3.19)*	(3.03)*	(4.71)*	(4.80)*	(4.70)*	(3.78)*
Corruption (lag)	-0.180	-0.594	-0.403	-0.997	-1.017	-1.083
	(0.75)	(1.63)	(5.18)*	(4.17)*	(3.82)*	(4.06)*
Anse (lag)	-0.015	-0.106	0.035	-0.002	-0.002	-0.022
	(0.38)	(1.73)***	(2.10)**	(0.05)	(0.04)	(0.37)
Corruption*anse (lag)	-0.010	0.022	-0.010	-0.011	-0.009	-0.005
	(0.76)	(1.03)	(2.29)**	(0.80)	(0.50)	(0.30)
Polity (lag)	0.054	0.043	-0.001	-0.052	-0.067	-0.085
	(1.38)	(0.84)	(0.04)	(1.48)	(1.74)***	(2.08)**
year	-0.098	-0.200	-0.103	-0.156	-0.166	-0.171
	(2.83)*	(2.17)**	(7.83)*	(4.92)*	(4.96)*	(4.99)*
Literacy youth male	-0.020					
	(1.14)					
Perc. Low Income		-0.120				
		(1.07)				
Rural pop density			0.000			
			(0.53)			
Unempl. youth male				0.040	0.043	0.040
				(1.57)	(1.67)***	(1.53)
Food exports (%)						-0.021
						(1.36)
Fuel exports (%)					0.013	
					(0.74)	
Constant	193.185	397.271	202.634	306.221	325.364	338.165
	(2.80)*	(2.16)**	(7.75)*	(4.85)*	(4.89)*	(4.93)*
Observations	140	104	1892	871	842	844
Groups	91	103	116	82	80	80

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

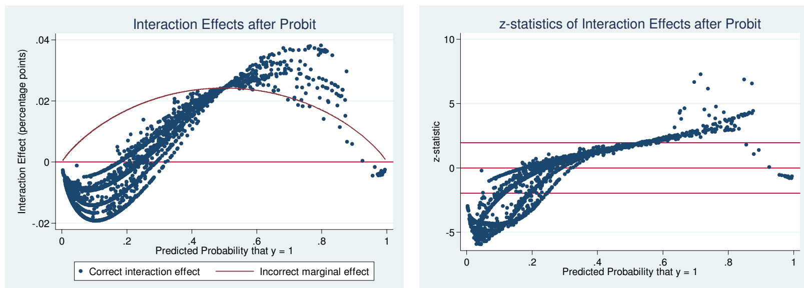


Figure 2.12: Interaction effect `bqua`, `nfd` (based on probit regression in Table5 col.2, in text)

Variables	*Dependent variable: inconflict5*					
	(1)*PanelProbit*	(2)*PanelProbit*	(3)*PanelProbit*	(4)*PanelProbit*	(5)*PanelProbit*	(6)*PanelProbit*
Gdp / capita (lag)	-0.000	0.000	-0.000	0.000	-0.000	-0.000
	(0.44)	(1.60)	(0.30)	(0.77)	(1.71)***	(2.02)**
Population (ln,lag)	0.928	0.570	0.623	-0.171	0.560	0.767
	(3.52)*	(3.58)*	(4.45)*	(0.83)	(4.32)*	(4.84)*
Corruption (lag)	-1.130	-0.859	-0.584	-0.221	-0.373	-0.493
	(3.85)*	(6.16)*	(5.81)*	(1.18)	(4.89)*	(4.98)*
anse	-0.106	-0.007	0.024	0.034	0.035	0.012
	(2.03)**	(0.22)	(1.11)	(0.97)	(2.20)**	(0.61)
Corruption*anse (lag)	0.022	-0.005	-0.008	-0.014	-0.011	-0.008
	(1.24)	(0.61)	(1.41)	(0.97)	(2.47)**	(1.40)
Polity (lag)	0.049	-0.031	-0.005	0.036	-0.002	0.009
	(1.23)	(1.17)	(0.29)	(1.05)	(0.15)	(0.49)
Year	-0.135	-0.164	-0.133	0.212	-0.105	-0.135
	(3.56)*	(7.57)*	(8.35)*	(5.00)*	(8.59)*	(7.57)*
Gini coefficient	0.024					
	(0.81)					
Total unemployment		-0.017				
		(0.59)				
Metal ore exports			0.016			
			(1.20)			
Arms imports						0.000
						(0.18)
Exports/imports						0.000
						(0.32)
Energy depletion					-0.112	
					(1.53)	
Peacebefore				-0.063		
				(2.44)**		
Constant	266.227	325.317	262.134	-418.605	207.287	266.592
	(3.52)*	(7.52)*	(8.28)*	(4.95)*	(8.51)*	(7.48)*
Observations	294	1155	1666	530	2014	1579
Groups	102	97	116	46	117	112

Note: Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 2.13: Robustness checks: additional controls 2

Chapter 3

Resource Dispersion and Trading Neighbours: A Spatial Perspective

3.1 Introduction

Most renewable resources are spatially heterogeneous with respect to relevant biological and economic variables, such as stock level, growth and mortality rates, the carrying capacity of the environment, or harvesting costs and effort applied. This heterogeneity is likely to have important implications both for domestic management regimes and for international policy interactions and externalities. There are numerous instances where resource exploitation by a country has transboundary effects. The majority of the world fish catch, for example, is drawn from national waters, and international marine jurisdiction frontiers do not mimic in any form marine life habitats or spatial patterns. Moreover, the advent of the new location technologies (especially in fishing) prompt spatially-tailored policy responses, in order to avoid irreversible depletion of resources.[108] One example in point is the notorious Canadian North Atlantic cod fishery collapse. The mismanagement disaster has had many ex-post rationalizations, one being that policy decisions such as TACs[109] and licensing were based on a spatially aggregated view of the data, while the stock was unevenly distributed. The resource was jointly harvested by Canada within its 200-mile Exclusive Economic Zone (EEZ) and by 'distant water fishing nations' represented by ICNAF[110] outside of the the Canadian EEZ. Overharvesting in the *offshore* fishery, due to the inability of ICNAF to enforce effort limitations when the pressure on the resource became too strong, led to stock collapse

[108] For a good introduction to the impact of space on fisheries management, see James Wilen (2004), "Spatial Management of Fisheries."
[109] Total Allowable Catch.
[110] International Commission for the Northwest Atlantic Fisheries, now North West Atlantic Fisheries Organization or NAFO.

in the MSY-managed[111] *inshore* Canadian fishery.[112] This sort of international free-riding problem occurs whenever a resource is transboundary in nature. The UN Fish Stocks Agreement,[113] distinguishes between "highly migratory" or "straddling" fish stocks. This paper concerns itself with the latter type. The literature documents many examples of significant overexploitation of transboundary resources due to inter-jurisdictional free-riding: from the pollock stock in the Bering Sea's Donut Hole, to groundfish on the Bank of Newfoundland, to the Norwegian herring and the Atlantic bluefin tuna.[114] Therefore, there is a perceived need for gaining new insights into how uneven spatial distribution and/or mobility of the resource is likely to bias the efficacy of existing management practices.[115]

The present model refers to transboundary resources that migrate between two jurisdictions as a result of congestion or relative population differences between adjacent environments. In this paper, there is an added layer of complexity concerning the impact of resource mobility on the strategic international interactions due to trade and proximity. Resource harvesting, by its stock reducing effect, can play a role in influencing migratory patterns. Also, with trade, the specialization patterns of the neighbours[116] are interconnected via the spatial dispersion of the resource, whenever resource sector productivity is stock-dependent. By contrast, when two countries simply exploit a shared resource[117] these dynamics, that constitute a distinguishing feature of our paper, are not present.

In a simple setting with two neighbouring trading partners sharing a mobile resource, this paper asks first whether we can expect the usual trade with renewable resources literature[118] results to hold and what is the nature

[111] Maximum Sustainable Yield used to be the policy target of choice, until it was shown to be neither prudent for stock conservation, nor optimal from an economic point of view.
[112] See Daniel Gordon and K. Klein (1999), p. 285 - 300.
[113] See *www.un.org/Depts/los/convention_agreements/convention_overview_fish_stocks.htm*.
[114] See Bjørndal and Munro (2003) for these and other examples as well as further references.
[115] Relatively recent progress in population ecology to understanding spatial patterns has the potential to make an important contribution in this effort. See the seminal work by Akira Okubo and Simon Levin (2001), *Diffusion and Ecological Problems: Modern Perspectives*.
[116] Throughout this paper, the term 'neighbours' is meant to designate any two countries that share a mobile resource and therefore includes countries separated by the sea.
[117] See, for example, the classical paper by Gordon Munro (1979), or the more recent work by Bulte and Damania (2005).
[118] In particular the Brander and Taylor 1997a, 1998 suite of papers and the literature they spawned.

of the changes implied by the added spatial dimension.[119] Also, as an extension, we look at incentives for the introduction of a resource management policy in the two countries in isolation and trade. In particular, is trade - given the spatial interdependence of the resource stocks - likely to stimulate policy cooperation between the two countries and create an escape route from the typical Prisoner's Dilemma?

The motivation for this paper relies on the observation that - in a basic scenario as described above - no linkage other than trade formally exists between the two countries when space is ignored, even though the two neighbours may be essentially sharing the same resource stock. On the other hand, specialization patterns are likely to be influenced by any stock migration when comparative advantage depends on the stock level.[120] Given these, the usual welfare and conservation results[121] may not hold. If the neighbour is a "consumer"[122], home's incentives to be a "consumer" as well may be high. If the neighbour is "conservationist", it may increase home's incentives to become a conservationist, too, as the payoff from any regulation is not decreased through free-riding. Several of the cases discussed in the paper refer to small open economies exploiting a mobile resource. This scenario can be applied to a diverse group of countries, with potential examples ranging from Ecuador, Peru and Chile sharing the east Pacific mackerel or anchovy stocks, to Indonesia and Australia's exploitation of straddling red snapper, to Mauritius and Seychelles exploiting the straddling stocks of dame berri and capitaine in the Western Indian Ocean.[123] In fact there is a widely shared view that straddling fish stocks are important especially for small islands having a limited continental shelf as part of a vast oceanic system. [124]

[119] Throughout the paper, references to the 'spatial dimension' of the model and 'spatial mobility' of the resource are used interchangeably. Space, the new element introduced here becomes relevant by providing another dimension (besides time) for the variation in the resource stock.

[120] And this has been the norm in the literature.

[121] e.g. 'complete specialization in manufacturing is not possible' or 'the country specializing in the resource good incompletely necessarily losses'.

[122] i.e. features unregulated open-access to the resource.

[123] For an exhaustive list of straddling fish resources around the world, see Jean-Jacques Maguire, Michael Sissenwine, Jorge Csirke, Richard Grainger and Serge Garcia 'The State of the World Highly Migratory Straddling and other High Seas Reasources' FAO Fisheries Technical Paper 495, Rome, 2006.

[124] 'Their reef resources are purely national, but their oceanic resources, which represent a large proportion of the marine resources available to them for development, are straddling...The situation makes the small island resources very vulnerable to high seas fishing...', according to S.M. Garcia of FAO's Fishery Resources

The previous literature on trade and renewable resources, much of which was stimulated by Brander and Taylor (1997, 1998), has focussed on cases where national resource stocks are independent. This paper shows that introducing spatial dispersion of stocks between countries can change some of the key results from that literature, while others generalize to a mobile-resource environment. For example, Brander and Taylor (1998) find that trade leads to resource depletion and welfare losses in an open-access resource-exporting country, while the country with a comparative advantage in the manufacturing good is unable to fully specialize, yet will always gain from trade. In contrast, I find that the country specializing in the resource may gain in terms of both conservation and welfare, while the one specialized in the manufactured good may lose from trade according to both criteria (though not concomitantly). Also, under some reasonable assumptions, it becomes possible for the larger country in the two-country case to specialize in the manufacturing good. Although allowing for dispersion could potentially allow for a wider array of outcomes even when one or both partners are diversified, it turns out that the traditional results are quite robust in that case. However resource mobility links the two economies even in autarky. Their comparative advantage when moving from autarky to free trade depends on the timing of their neighbour's opening up to trade and additional results, such as comparative advantage reversals can obtain. While in autarky, resource management incentives are weakened by the neighbour's free riding, opening up to trade improves these incentives. When the neighbour specializes in the manufacturing good, the free riding resource absorbtion effect that is manifest in autarky disappears. In sum, spatial resource mobility can change several results in the literature, as dispersion creates another level of interdependence between neighboring countries (beside trade), and alters incentives.

The effort to incorporate geographic considerations in economic models is not new. There are many notable achievements, beginning with von Thünen's bid-rent model and its applications in urban economics, to the agglomeration effects in the increasing returns to scale and trade frictions 'new' trade literature. Yet, making the model richer often comes at a cost: a common feature of these works seems to be that they trade simplicity - and sometimes tractability - for realism and explanatory power. This paper is also based on the premise that, although accounting for spatial patterns complicates the analysis, there may be important insights to be gained from

Division. See *www.oceanatlas.com/world_fisheries_and_aquaculture/html/resources/capture/highseas/straddling_stocks.htm.*

acknowledging its effects.

Until recently, spatial dimensions of resource population dynamics have been largely ignored in the economic literature on renewable resources, as they complicate the simple canonical models (i.e. Gordon, Smith). Yet, some resources move around significantly and treating the resource stock as being spatially homogeneous may - in those instances - generate misguided policy. Recent steps which introduce space into renewable resource models have been made in papers such as Brock and Xepapadeas (2004), who analyze reaction-diffusion processes that are capable of inducing spatial heterogeneity. Focusing on the Turing mechanism (also used in core-periphery models) and treating space as continuous, they derive a Pontryagin principle for optimal control with diffusion. Sanchirico and Wilen (1999, 2005) discuss the optimal policy under intertemporal and spatial dynamics. Space is discrete, effort is allocated dynamically among patches according to their relative profitabilities. The earlier paper discusses partial equilibrium under five scenarios: fully integrated, closed patches, sink-source, multiple source, spatially linear, while the second paper shows how optimal location-specific management depends on matching economic and biological characteristics of the patches. Still there are relatively few spatially-explicit studies so far, and to the best of my knowledge, none includes trade, international dimensions or endogenous resource management.

Other literature, related in objectives but not modeling space, include Chichilnisky (1994) where the South (featuring incomplete property rights) loses when trading with the North (having better management), because of the worsening of the open-access resource depletion, Brander and Taylor (1997b) where, unlike in Chichilnisky, both countries may gain, since comparative advantage in the resource may switch to the 'North' due to better management, Brander and Taylor (1997a, 1998), where the country specializing incompletely in the open-access resource necessarily loses from trade. Hannesson (2000) models a small open economy with decreasing returns to scale in the non-resource sector, and shows that there may be an 'immiserizing effect' of resource management if demand is inelastic, while Emami and Johnston (2000), in a two-country trading equilibrium argue that unilateral management can have immiserizing effects. Bulte and Damania (2005) present a model of two countries jointly exploiting a resource stock where they show that management policies are strategic substitutes in autarky and in the two-country model (i.e. when price is endogenous), and they are strategic complements in the small open-economy case (i.e. when price is exogenous). In Copeland and Taylor (2005) pollution policy in one country can generate self-interested endogenous pollution policy in the other country. This occurs via an income effect that dominates a free-riding effect and a substitution ('carbon leakage') effect.

The rest of this paper proceeds as follows: in order to build intuition and present the basic components of the model in a simple setting, the second section looks at the small economy case with the resource spread over two jurisdictions, one domestic and one foreign. Then in the third section, the analysis moves to a two-country framework, where conservation and welfare implications of trade are discussed. The fourth section explores the implications of unilateral resource management and the scope for policy cooperation. The fifth section concludes and proposes several extensions.

3.2 The Small Open Economy Model

A simple Ricardian trade with renewable resources general equilibrium model is presented below for the small open economy. Results from the initial derivation are used in the third part when the international price formation is endogenized in a two-country setting.

3.2.1 Autarky

The model proposed here is the resource dispersion-augmented standard Brander and Taylor (1997). The evolution of the stock level depends here not only on the natural growth and harvesting, like in the classical spatially-static bioeconomic model, but also on the movement of the resource in and out of the patch of interest. This section captures in a simple way the implications of resource mobility on this economy, even when markets are separated. The growth of the renewable resource stock $S(t)$ takes the form:

$$\dot{S} = G(S) + D\left(S, S^*\right) - H(S), \tag{3.1}$$

where

$$G(S) = rS\left(1 - \frac{S}{K}\right)$$

and

$$D(S, S^*) = \delta S\left(\frac{S^*}{K^*} - \frac{S}{K}\right).$$

G is the the logistic natural growth function with parameters r (the intrinsic growth rate) and K (carrying capacity of the environment) and D is the dispersion function with parameter δ, the dispersion coefficient. The standard net growth function is modified to include dispersion, which takes into account the fact that - for reasons such as the availability of food and reproductive space - the resource tends to flow to the area where relative carrying capacity is greater.[125]

Supply of the resource is secured via harvesting H, which takes the Schäffer form, where q is the productivity coefficient depending on location technology, boat capacity etc., and L_H is the amount of labour optimally allocated to the resource sector.

$$\text{Harvesting good production: } H = qSL_H \tag{3.2}$$

The non-resource sector output is a constant returns to scale function of the allotted labour only:

$$\text{Manufacturing good production: } M = L_M. \tag{3.3}$$

If we denote by p the relative price of the resource good,[126] free-entry into both industries amounts to zero profits and unitary wages:

$$w = pqS \text{ and } w = 1 \Rightarrow p = \frac{1}{qS} \tag{3.4}$$

and an expected result obtains: the autarkic price of the resource good is inversely related to the stock level and to harvesting efficiency.

The representative consumer in this economy has preferences represented by a simple Cobb-Douglas utility function and solves:

$$\underset{H,M}{Max} \quad U = H^{\beta}M^{1-\beta}$$

subject to the budget constraint that $pH + M = w$. The right hand side of the budget equation consists only of labour income, since resource rents are dissipated under open-access. The solutions are constant shares of real income: $H = \frac{\beta w}{p}, M = (1-\beta)w$ and aggregate demands, given unitary wages are: $H = \frac{\beta L}{p}, M = (1-\beta)L$. Imposing the market clearing conditions reveals that the optimal labour allocation under autarky is:

$L_H = \beta L$ and $L_M = (1-\beta)L$.

The open-access resource stock is in equilibrium when natural growth and net inward dispersion just make up for the amount harvested, or when: $\frac{dS}{dt} = 0$, which is equivalent to:

$$H(t) - D(t) = G(S(t)). \tag{3.5}$$

125 See Appendix (1) for an extended discussion of the functional form of dispersion. Results here are based on the algebraically-friendlier Option II specification.

126 i.e. $p = \frac{p_H}{p_M}$.

Using the specifications mentioned above, the steady-state stock level can be written as:

$$S^{SS} = \frac{K}{r+\delta}\left(r + \delta\frac{S^*}{K^*} - q\beta L\right). \tag{3.6}$$

It can be easily seen that the equilibrium stock level is increasing in the relative abundance of the adjacent resource patch. It now becomes possible, using (3.4), to solve for the autarkic equilibrium price $p = \frac{r+\delta}{Kq} \cdot (r + \delta\frac{S^*}{K^*} - q\beta L)^{-1}$, and then to use it to find equilibrium autarkic quantities as follows: $H = q\beta L \cdot \frac{K}{r+\delta} \cdot (r + \delta\frac{S^*}{K^*} - q\beta L)$ and $M = (1-\beta)L$.

The following two propositions describe the autarkic equilibrium in this simple setting, where no assumptions are made yet about the resource exploitation regime in Foreign.

Proposition 1: *The domestic resource is viable if domestic population is not too large relative to the own-patch resource parameters and abundance in the adjacent patch. The autarkic steady-state stock is higher with r, δ and lower with L, q and β.*

It is readily shown from (3.6) that a positive autarkic steady-state stock exists provided that $L < \frac{r+\delta S^*/K^*}{q\beta}$. As expected, a very high population level, catchability (productivity) coefficient and a strong consumer taste for the resource good can lead to extinction, especially when coupled with a low intrinsic growth rate, dispersion coefficient and 'non-domestic' relative stock. When the relative stock in Foreign is also written explicitly- under symmetrical autarkic open-access assumptions -, a positive autarkic stock obtains for $\frac{r}{(r+\delta)L+\delta L^*} > (1+2\delta)q\beta$. In Brander and Taylor (1998), this condition is simply: $\frac{r}{L} > q\beta$, and it is interpreted as a threshold 'factor proportions' condition. The same interpretation can be given here: a positive steady-state stock of the resource exists starting from a certain level of resource abundance (adjusted for dispersion) relative to a weighted sum of the two populations.

Re-arranged, the relationship between the two relative resource stocks suggests the scope for inter-jurisdictional free-riding in this framework, since inward dispersion can compensate for heavy local harvesting. This is emphasized in the next result. The long-run autarkic Production Possibilities Frontier can be written as: $H = qS(L-M)$. Plugging in the equilibrium stock level from (3.6) we obtain that $H = \frac{qK}{r+\delta}\left(r + \delta\frac{S^*}{K^*} - q\beta L\right)(L-M)$ is the linear PPF. The following then holds:

Proposition 2: *A reduction in the 'foreign' steady-state stock of the resource reduces the 'home' stock, productivity in the resource good and shrinks* *the autarkic PPF, reducing welfare.*[127]

This is due to the fact that the autarkic economy remains necessarily diversified. The inverse is also true, namely: an exogenous increase in the foreign stock S^* leads - via an H-productivity increase due to the resource becoming more abundant via dispersion - to an increase in welfare at Home.

An important aspect to notice here is that even in autarky, stocks in both Home and neighbouring patch (i.e. S and S^*) are rendered endogenous by dispersion, and the K-relative values can be expressed in terms of the parameters as follows:[128]

$$\left(\frac{S}{K}\right)_A = 1 - \frac{q\beta}{r(r+2\delta)}[(r+\delta)L + \delta L^*] \tag{3.7}$$

and symmetrically for the neighbouring country:

$$\left(\frac{S}{K}\right)^*_A = 1 - \frac{q\beta}{r(r+2\delta)}[\delta L + (r+\delta)L^*]. \tag{3.8}$$

Given these expressions, dispersion into the Home patch is $D = \delta S \frac{q\beta}{r+2\delta}(L - L^*)$, positive when Home is the larger country. Moreover, the prices can be readily calculated using (3.4). The autarkic relative price of the resource good at Home is:

$$p^A = \frac{1}{Kq}\left\{1 - \frac{q\beta}{r(r+2\delta)}[(r+\delta)L + \delta L^*]\right\}^{-1}. \tag{3.9}$$

Like in Brander and Taylor (1997),[129] the autarkic price is a function of the domestic relative abundance $\frac{r}{L}$. In addition, this price is also dependent here on the Foreign population, as well as on the strength of dispersion. Then, equilibrium quantities can be easily calculated as a function of parameters. For instance, when both Home and Foreign are in autarky, the demand for the harvesting good at home can be expressed as:

$H_{A/Foreign_A} = \frac{q\beta KL}{r+\delta}\left\{r + \delta - q\beta\{L + \frac{\delta}{r(r+2\delta)}[\delta L + (r+\delta)L^*]\}\right\}.$

The analysis goes into further detail below, focusing on the direct implications of relative stock levels for the pattern of specialization. Here it suffices to notice that what is important for the dispersion and later for the pattern of trade is the population level and the carrying capacity of the environment in the two countries, all other parameters being assumed

127 Note that here the production and consumption possibilities frontiers coincide.
128 The subscript A indicates autarky.
129 See for example p. 535.

the same. An increase in population in the neighbouring (Home) country decreases the stock, the optimal harvest, increases the price of the resource good at Home (neighbour) and lowers welfare. This latter implication can be easily seen from the fact that consumer indirect utility function depends negatively on the relative price of the resource good H.

$$v(p) = \beta^{\beta}(1-\beta)^{1-\beta}p^{-\beta}. \tag{3.10}$$

This simple framework also illustrates the free-riding implications of any policy that has a conservationist effect when the resource is mobile. Abundance in one patch is intrinsically related to abundance - and therefore to the level of exploitation - in the neighbouring patch, even with no trade in goods. We turn next to the additional implications brought about by trade.

3.2.2 The Two Small Open Economies Equilibrium

Let p^A and p^w be the Home country's autarkic, and the world relative price of the resource good, respectively. When the small economy Home opens up to trade with the rest of the world, it takes the external price as given. The resource parameters and exploitation regime in Foreign is also relevant for Home, due to resource dispersion. Various specialization and trade patterns of one country can have different implication insofar as the own resource stock and welfare effects are concerned, as well as regarding its neighbour's comparative advantage, gains from trade and conservation. The following paragraphs focus on the differences with the previous models introduced by resource mobility.

Home has a comparative advantage in the resource good

As a first case, if $p^A < p^w$, the Home country specializes in the harvesting good. The Brander and Taylor (1997) result that the resource exporter tends to become diversified and lose in the long run can potentially be prevented. In particular, the country specializing in the resource good loses *only if* the inward dispersion does not dominate increased depletion.

Proposition 3: *A 'good' (i.e. conservationist) neighbour*[130] *can make specialization in the resource good possible and profitable.*

Adding to the compensation coming from the logistic functional form, specialization in H has an extra (free riding) compensatory effect by reducing

[130] Here this means a high enough neighbouring resource stock S^*.

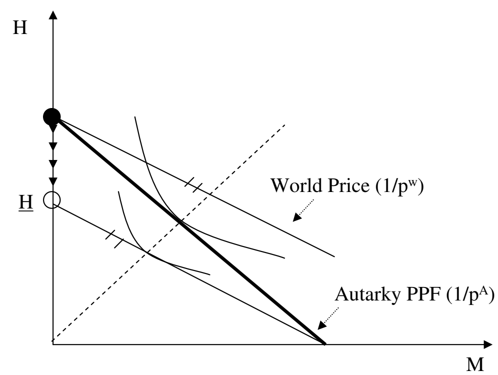


Figure 3.1: Home has a comparative advantage in H

the relative stock level and therefore inducing dispersion from the neighbouring patch. A resource good-specialized trading steady-state, in addition to $\dot{S}=0$, also requires that $S > \frac{1}{qp^w}$, or that the resource is sufficiently abundant (relative to world demand) for the country to keep its comparative advantage in H. It can be easily shown from (3.6) that as long as dispersion is strong enough, namely $\frac{S^*}{K^*} > \frac{1}{\delta}\left(\frac{r+\delta}{Kqp^w} + q\beta L - r\right)$, the harvesting productivity does not decrease too much so that the small open Home economy remains specialized in H. This is obviously more likely the higher p^w is, and the fewer the labour that has to be employed in the resource sector L. If this condition holds, Home will gain in welfare terms by maintaining a sufficient level of the resource stock.

To make matters more concrete, assume that the neighbour of this small open economy is in autarky. Note that for this scenario to be possible, 'Foreign' has to be just one of many foreign countries. In other words, we have two small economies: Home and Foreign, and the trading rest of the world. There is a multitude of cases possible, corresponding to all the specialization permutations between the two neighbours. To focus the analysis, assume Foreign is in isolation. The analysis is symmetrical when Foreign is trading as Home is autarkic. When Home is specialized in H and Foreign is closed to trade, the relative resource stocks will have the following expressions:[131]

$$\left(\frac{S}{K}\right)_{H/Foreign_A} = 1 - \frac{q}{r(r+2\delta)}[(r+\delta)L + \delta\beta L^*] \tag{3.11}$$

and

$$\left(\frac{S}{K}\right)^*_{A/Home_H} = 1 - \frac{q}{r(r+2\delta)}[\delta L + \beta(r+\delta)L^*]. \tag{3.12}$$

The scenario in which the Home country remains specialized in H when Foreign is autarkic is feasible as a steady-state equilibrium if $\frac{S}{K} > \frac{1}{qKp^w}$, or equivalently if the world relative demand is 'sufficiently strong' so the following holds:

$$p^w > \frac{1}{Kq\left\{1 - \frac{q}{r(r+2\delta)}[(r+\delta)L + \delta\beta L^*]\right\}}. \tag{3.13}$$

As long as this condition is satisfied, the H-specialized Home can gain from trade when Foreign is in autarky. If this condition does not hold, Home will eventually become diversified and may lose from trade in the long run, despite free-riding on its neighbours' resource. If inward dispersion is insufficient, the stock will fall enough so that the economy may become diversified in equilibrium. In Figure 3.1, this happens when the vertical intercept of the PPF drops all the way to $\underline{\text{H}}$. Even though in our case the mobility of the resource prolongs the transition from temporary specialization in H to a steady-state diversified equilibrium, the small resource exporter may now still lose in the long run, just like in Brander and Taylor, when the Consumption Possibilities Frontier contracts inside the autarkic PPF, although, again, this does not necessarily have to happen. An important difference with the Brander and Taylor models is that the pattern of specialization depends crucially on the neighbouring relative stock, which raises the additional strategic implications.

How does the resource flow in this scenario? The resource is dispersed from Foreign to Home in this steady state, reinforcing the comparative advantage, if $(\frac{S}{K})_{H/Foreign_A} < (\frac{S}{K})^*_{A/Home_H}$, which is equivalent to:

$$\beta L^* < L. \tag{3.14}$$

Notice that this inequality amounts to Home being 'large enough' *relative* to its neighbour, and it is always true when Home is the larger country. In

[131] See Appendix (2) for the derivation. Subscript $H/Foreign_A$ indicates that Home is specialized in the resource good given an autarkic Foreign, while subscript $A/Home_H$ indicates that Foreign is autarkic given the H specialized Home.

this case dispersion flows from Foreign to Home both in autarky (from (3.7) and (3.8)) and with trade. If Home is the smaller country ($L < L^*$) and thus $D < 0$ under autarky, opening up to trade as specialized in the resource good may induce a favourable change in dispersion: if $L > \beta L^*$, the trading Home free rides on its neighbour's resource. Having still a relatively large population, Home has the capacity to deplete its resource relatively more, so as to attract resource from its neighbour. Re-writing the condition as: $\beta < \frac{L}{L^*}$, it can also be interpreted as requiring that the preference for the resource good is 'not too strong' compared to the relative population sizes: harvesting for autarkic consumption of the resource good in Foreign is below that in the specialized Home. Notice that while (3.14) shows the direction of resource flow, condition (3.13) is ultimately important for determining the welfare results for Home. An *absolutely* small L (also a small L^*) increases the chances for sustainable full specialization, while a *relatively* large L (versus L^*) allows for resource dispersion to reinforce Home's comparative advantage in H.

When Foreign is not trading and the small open Home economy specializes in harvesting and increases the pressure on the resource, H-sector labour productivity in the diversified autarkic Foreign decreases, the price increases and welfare there decreases, as it is shown in the previous section. Thus, a country's opening to trade can have negative welfare effects on its neighbour, (even) when the neighbour itself is not trading. The timing of trade liberalization is important here. If both countries open up to trade with the world, but not simultaneously, the country specializing in H first may in fact pre-determine the neighbour's specialization in M, which may subsequently secure long-run gains from trade as a manufactures' exporter. This takes place if the additional depletion of the stock triggered by Home's H-specialization is significant enough to push Foreign's autarkic relative price above the international price.

The expression in (3.12) provides the value of the stock in autarkic Foreign, given the specialization of Home in the resource good. Foreign can then itself specialize in H when $p^*_{A/Home_H} < p^w$, or when

$K^* \left\{1 - \frac{q}{r(r+2\delta)}[\delta L + \beta(r+\delta)L^*]\right\} > \frac{1}{qp^w}$. One can note that the likelihood this is the case is reduced by the fact that Home already allocates all of its labour to harvesting, instead of just a fraction. Moreover, it is possible that - due to Home's specialization in H - Foreign's comparative advantage in M is pre-determined. This takes place when $p^w < p^*_{A/Home_H}$, condition equivalent to $p^w < \frac{1}{qK^*\left\{1 - \frac{q}{r(r+2\delta)}[\delta L + \beta(r+\delta)L^*]\right\}}$. Concomitantly, recall that for Home to stay specialized in H in the steady state we need to have $p^w > \frac{1}{qK\left\{1-\frac{q}{r(r+2\delta)}[(r+\delta)L+\beta\delta L^*]\right\}}$. The simultaneous satisfaction of both inequalities is possible for a range of world price levels and whenever the following holds: $\frac{K}{K^*} > \frac{r(r+2\delta)-q[\delta L+\beta(r+\delta)L^*]}{r(2+2\delta)-q[(r+\delta)L+\delta\beta L^*]}$, which boils down to the Home environment being sufficiently more accommodating for the resource. Under such conditions, a 'historical' specialization in the resource of one neighbour leads to the other neighbour acquiring a complementary comparative advantage, which is unambiguously welfare improving in this two-small open economy case.[132]

Home has a comparative advantage in the manufacturing good

As a second case, if trade opens with $p^A > p^w$, a manufacturing-specialized Home allows the resource stock to recover in both patches and may 'create' a comparative advantage in harvesting for the autarkic Foreign. Appendix (3) calculates the following expressions for the two steady state resource stocks under such a scenario:

$$\left(\frac{S}{K}\right)_{M/Foreign_A} = 1 - \frac{q\beta}{r(r+2\delta)}\delta L^* \tag{3.15}$$

and

$$\left(\frac{S}{K}\right)^*_{A/Home_M} = 1 - \frac{q\beta}{r(r+2\delta)}(r+\delta)L^*. \tag{3.16}$$

Two things are noteworthy here. First, the steady state resource levels in both countries are independent of the size of the Home country. Indeed, since Home is a small open economy taking the relative price as given and importing all of its resource good from abroad, this is not particularly surprising. Secondly, note that the relative resource stock in the autarkic Foreign is strictly below the one in the M-specialized trading Home, thus dispersion will take place towards the Foreign patch, contributing to the possible 'induction' of a comparative advantage in the resource good there, should the Foreign economy become open to trade. This endogenous CA creation takes place when two conditions are met: the relative autarkic price of the harvesting good in Foreign exceeds the world price when Home is also closed to trade and diversified, (i.e. Foreign has a potential CA in M), and this price drops below the world price as a result of Home specialization in M. The first condition is equivalent to: $\frac{L}{L^*} > \frac{r}{r+\delta}$ and is more likely for relatively

[132] This can change in the two-country case, as shown in the third section.

smaller foreign population, while the second entails: $\frac{1}{qK^*\left\{1-\frac{q\beta(r+\delta)L^*}{r(r+\delta)}\right\}} < p^w$, and is also more likely the smaller the Foreign population and taste for the resource, and the larger the combined growth rate (biological and due to dispersion). The specialization patterns of the two neighbours are thus interconnected and may become complementary even when they are small open economies facing an exogenous international price.

Home will export the manufacturing good M and gain in the long-run if fully specialized, exactly like in the Brander and Taylor (1997) framework. These effects are illustrated in the graphs in Figure 3.2, where complete specialization in either good is welfare improving. In the pictures, the resource stock follows the usual dynamics of decreasing in the exporter and increasing in the importer of the harvesting good. However, unlike in those

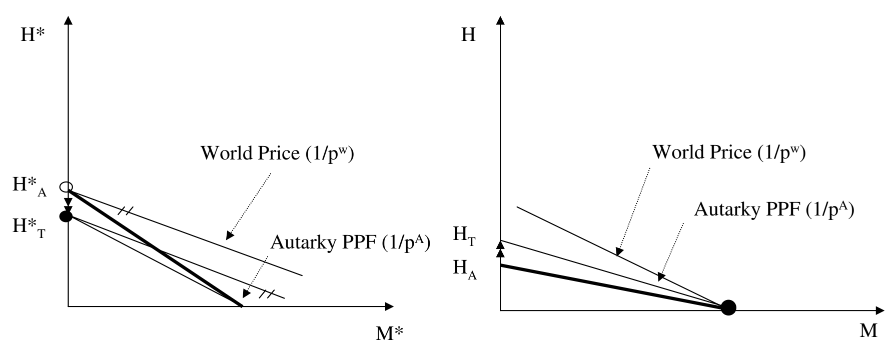


Figure 3.2: Home has a comparative advantage in M

models, the stock does not necessarily recover following specialization in M. This depends, again, on the level of exploitation in the neighbour's patch. The Home country could also benefit when becoming diversified in the long run, as a result of a sufficient net resource growth resulting from the specialization pattern.

Proposition 4: *When in a trading equilibrium the small economy is specializing in manufacturing, a 'bad' (i.e. consumerist) neighbor depletes own stock and reinforces the pattern of comparative advantage. There is however no negative welfare effect for the Home economy, as long as it remains specialized.*

It can be noticed, by comparing expressions (3.15) and (3.7), that the scenario in which Home reaches a specialized trading equilibrium exporting

M and Foreign is closed has conservationist consequences for the Home. This result, however, depends on the fact that exploitation in Foreign is bounded by domestic demand. If Foreign were to start trading, taking advantage of the complementary creation of a comparative advantage in the resource good, the resource stock situation at Home could change.

In particular, when Home specializes in M and Foreign specializes in H, the relative levels in the two regions are the following:[133]

$$\left(\frac{S}{K}\right)_{M/Foreign_H} = 1 - \frac{q\delta}{r(r+2\delta)}L^*, \tag{3.17}$$

and

$$\left(\frac{S}{K}\right)^*_{H/Home_M} = 1 - \frac{q(r+\delta)}{r(r+2\delta)}L^*. \tag{3.18}$$

In addition to resource parameters, the stocks depend only on the harvesting ability of the Foreign labour force. Note also that relative stock is higher at Home, and so dispersion reinforces comparative advantage. The resource stock at Home can then be less than under autarky when the neighbour is exporting the harvesting good. The condition for this 'resource capture' effect to occur is: $\left(\frac{S}{K}\right)_{M/Foreign_H} < \left(\frac{S}{K}\right)_A$, which is equivalent to:

$$\frac{L^*}{L} > \frac{(r+\delta)\beta}{\delta(1-\beta)}, \tag{3.19}$$

or the relative size of the neighbour should be large enough compared to the stock replenishment and relative preference parameters. In the first graph of Figure 3.3, productivity in H falls due to attracted dispersion, even as the Home country is specializing in the non-resource good.

An equivalent counter-intuitive stock effect of international trade specialization occurs for Foreign when the resource becomes more abundant via dispersion, despite the intensification of exploitation. Such a 'resource absorption' effect, illustrated in the second graph of Figure 2.3, takes place when $\left(\frac{S}{K}\right)^*_{H/Home_M} > \left(\frac{S}{K}\right)^*_A$, and this occurs when:

$$\frac{L^*}{L} < \frac{\beta\delta}{(1-\beta)(r+\delta)}. \tag{3.20}$$

These two 'perverse' stock effects cannot occur concomitantly. If, for instance, Home's resource level drops below the autarkic level, it is because

[133] See Appendix (4) for the algebra.

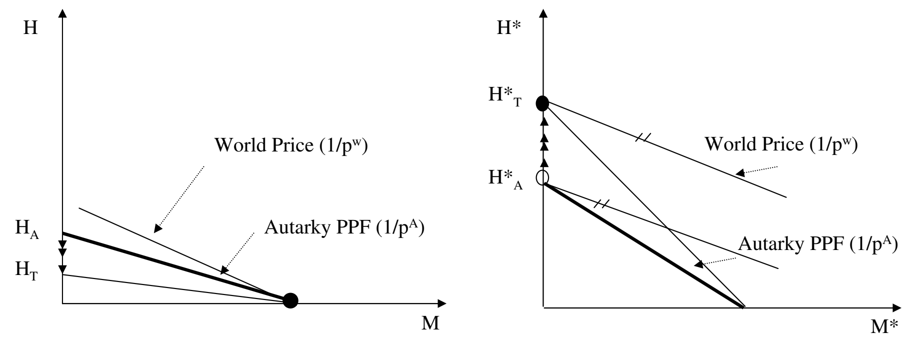


Figure 3.3: 'Perverse' resource stock effects

the strength of the world demand dictates a significant increase in harvesting in Foreign and a reduction of the absolute magnitude of the stock there too. Conversely, if the Foreign resource stock level rises above the autarkic value, a relatively low world price determines a moderate level of harvesting increase in Foreign, which will fail to induce excessive inward dispersion from the neighbouring resource patch. When (3.19) is satisfied and (3.20) is not, both countries experience negative resource stock effects compared to autarky, thus trade may create an incentive for resource policy cooperation. When (3.20) holds and (3.19) does not, both countries gain in terms of conservation by specialization according to their comparative advantage and trade.

The neighbours have comparative advantage in the same good

Another possibility is that the resource is abundant in the *region* formed by the two countries relative to the rest of the world, so that both countries are trading as specialized in the resource good. The steady-state values of relative stocks in this scenario are:

$$\left(\frac{S}{K}\right)_{H/Foreign_H} = 1 - \frac{(r+\delta)qL + \delta qL^*}{r(r+2\delta)}$$

and

$$\left(\frac{S}{K}\right)^*_{H/Home_H} = 1 - \frac{(r+\delta)qL^* + \delta qL}{r(r+2\delta)},$$

where the condition for long-run specialization is that the world demand is strong enough (or the two countries are small enough), so that $p^w > \frac{1}{qS}$ and

$p^w > \frac{1}{qS^*}$. In this case the resource can accommodate the entire workforce in both countries to be employed in the resource sector. Notice that a free riding effect of exploitation due to dispersion manifests itself here also: in the steady-state the resource disperses from the smaller country towards the larger one. As long as the relative world demand is strong enough and the two population levels are such that the resource is viable in both Home and Foreign, this trade pattern is sustainable. It is also possible, however, that both countries open up to trade specialized in H but in the long run only the larger country manages to stay specialized, while the smaller country is then pushed to become diversified, or even witnesses a comparative advantage switch into manufacturing. While losing in conservation terms, the smaller country can gain in welfare terms when it experiences a reversal of its export pattern.

The polar opposite of the last scenario, namely the one in which both countries are specialized in M as they trade with the world is also possible in this two small open economies case. Resource stocks in both patches are allowed to grow to equal the carrying capacity of the environment and no dispersion occurs in the long-run. This happens when the relative world price of the resource is small enough, or when the productive capacity of the two countries as represented by their harvesting productivity and the carrying capacity of their environment is low: $p^w < \frac{1}{qK}$ and $p^w < \frac{1}{qK^*}$. Both of these complete specialization cases with identical comparative advantage are very similar to the one-country analysis, with both countries gaining from trade in welfare terms (in the second case also in conservation terms).

When the two small open economies trade with the world according to complementary comparative advantage patterns, namely Home specialized in M and Foreign in H, and when, despite relative stock-dependent dispersion, the resource decreases in Foreign and increases at Home, one or even both countries can eventually become diversified. If the world price is such that $S_{M/Foreign_H} \geq \frac{1}{qp^w}$, Home becomes diversified, while the same occurs for Foreign when $S^*_{H/Foreign_H} \leq \frac{1}{qp^w}$. In this case, the welfare effects parallel those in Brander and Taylor (1997): the manufacturing exporter gains, while the harvesting good exporter loses in the long run.

The idea which arises from these exercises is the following: introducing resource stock mobility to add to the 'factor content' exchange via international trade can easily overturn or expand many of the results obtained in the literature. There is a direct material exchange of one factor of production in addition to the indirect one via trade. As it was shown above, a larger array of cases become possible, including endogenous comparative advantage creation, comparative advantage reversal and 'perverse' resource stock effects. While the results can be very different on the conservation dimension from the benchmark Brander and Taylor (1997), the welfare findings are at the limit similar. The small open economy analysis above took the neighbouring economy into account implicitly. Due to the obvious strategic implications, it may be instructive to also look at the two-country setting and at the interplay between specialization effects, stock dynamics and welfare.

3.3 The Two-country Model

To explore the effect of one country's resource exploitation and trade on the rest of the world via changes in the international price, suppose now that the two neighbours trade (mostly) with each other, so the international price is endogenous. Assume the countries are similar, except for the environmental parameter K and population L.[134] If the two resource areas would be identical, the interesting interaction of spatial distribution and trade would vanish: if $K = K*$ and, say, $S_A < S_A^*$ to start with, then in autarky resource flows from Foreign to Home and dispersion tends to equalize not only relative, but also absolute stock levels. Consequently, if trade starts from a previously reached autarkic steady-state and given the equal-productivity assumption, the two countries will have the same autarkic relative prices and will not trade. Suppose then that $L \neq L^*$ and $K \neq K^*$. We also assume for now that there is domestic open-access to the resource and free entry into both industries.

Using the above specifications for preferences and technologies, relative demands are identical: $RD_{H/M} = \frac{\beta q S L}{(1-\beta)L} = \frac{\beta}{p(1-\beta)} = RD^*_{H/M}$. Also, the relative supply at Home at any point in time is $RS_{H/M} = 0$ if $p < \frac{1}{qS}$ and $RS_{H/M} = \infty$ otherwise. Similarly for Foreign, short-run supply $RS^*_{H/M} = 0$ if $p < \frac{1}{qS^*}$ and $RS^*_{H/M} = \infty$ otherwise. If we assume that $S_A < S_A^*$,[135] then trade will begin with Foreign specializing in H and Home in M, scenario represented in Figure 3.4.

The next subsection explores the evolution of the resource stock and the specialization patterns it determines, as well as the determination of international relative price. Following this discussion, the subsequent section

[134] The literature also assumes sometimes different intrinsic growth rates of the resource, yet this is not a sensible assumption here due to stock migration. It is possible, though, like in the multi-species scenarios, to keep track of a specification where $r \neq r^*$.

[135] When there is no SS dispersion $\left(\frac{S_A}{K} = \frac{S_A^*}{K^*}\right)$, this is equivalent to K being not too large relative to K^*.

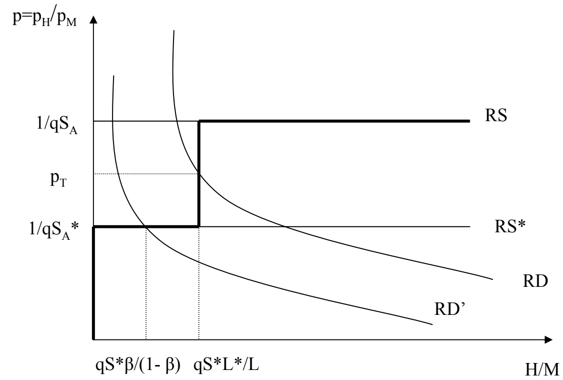


Figure 3.4: Relative Demand and Relative Supply

looks at the conservation and welfare implications for the two neighbouring trading partners.

3.3.1 Resource Stock Dynamics and the Pattern of Trade

When the two countries open up to trade with one another, the autarkic steady-state stock will determine specialization. Here we briefly look at both the diversified and specialized trading scenarios. The expressions for the relative stocks are as provided in equations (3.7) and (3.8) above: $\left(\frac{S}{K}\right)_A = 1 - \frac{q\beta}{r(r+2\delta)}[(r+\delta)L + \delta L^*]$ and $\left(\frac{S}{K}\right)^*_A = 1 - \frac{q\beta}{r(r+2\delta)}[\delta L + (r+\delta)L^*]$.

Is dispersion taking place when the countries start trading with each other? It can be easily noticed that as long as population/workforce sizes differ across countries, the relative autarkic stocks will be different, generating dispersion. Confirming the intuition,

Proposition 5: *Resource will disperse from the smaller to the larger country in a two-country long-run autarkic equilibrium. The larger country can specialize in manufacturing in a long-run trading equilibrium.*

Relative steady-state autarky resource stock will be higher for the smaller country. If $L > L^*$ then it can be easily seen from the expressions above that $\left(\frac{S}{K}\right)_A < \left(\frac{S}{K}\right)^*_A$ and there will be a net resource flow from the Foreign to the Home patch. Similar to the benchmark papers, comparative advantage is driven by the 'relative abundance' of the factors.[136] When the intrinsic growth rate of the resource is the same across countries, however, comparative advantage is decided by parameters L and K: $K < K^*$ and $L > L^*$ (i.e. smaller carrying capacity of the environment and larger population at Home) are *sufficient* conditions for the autarkic absolute stock level to be also lower at Home, and thus for Foreign to start trading having a comparative advantage in the resource good.[137] The second part of the proposition above is a result particular to our framework. In Brander and Taylor (1998), neither country could specialize in manufactures, and the reason was simple: specialization in the non-resource good allows the resource stock to recover, potentially up to its carrying capacity and increases productivity in the sector up to the point where it becomes lucrative to start producing it.[138] This effect is modified in our setting, where Home can specialize in manufacturing, as the extra resource is vented via dispersion to the neighbouring patch.

The interplay between stock migration and depletion due to harvesting determines the stability of the comparative advantage pattern. Depending on the carrying capacity parameters, the trading equilibrium can be diversified or specialized for $K \neq K^*$; as mentioned before, when $K = K^*$ there will be no trading in the steady state.

Suppose the countries start trading when $S_A < S_A^*$ with Foreign fully specialized in H and Home fully specialized in M. Then S^* falls due to harvesting and may increase or decrease due to dispersion. Similarly, S increases due to the diminished pressure on the resource from the harvesting industry, but may as well fall if outward dispersion effect exceeds the conservationist effect of this specialization. If the net effects are negative, reversal of the comparative advantage pattern may occur. In a specialized trading steady-state, stock levels can have convergent or divergent trends, which - in turn - determine the stability of the comparative advantage pattern.

Proposition 6: *i. When trade begins, if dispersion runs from the smaller country Home to Foreign, then Foreign specialization in H*[139] *stimulates further migration into the Foreign patch and the comparative advantage*

[136] Recall that in Brander and Taylor (1998) relative resource abundance is given by r and L.

[137] There is a fairly complicated restriction on parameters that is *necessary* for this: $\frac{r(r+2\delta)(K^*-K)}{q\beta} > L[K^*\delta - K(r+\delta)] + L^*[K^*(r+\delta) - K\delta]$. A less restrictive *sufficient* condition for this to hold are our simple assumptions of $L > L^*$ and $K < K^*$.

[138] See op. cit., Proposition 4, p. 193.

[139] $S^* > S$ is now possible when K^* is sufficiently larger than K, i.e. $\frac{K^*}{K} > \frac{S^*}{S} = \frac{r(r+2\delta)-q\beta[(r+\delta)L+\delta L^*]}{r(r+2\delta)-q\beta[\delta L+(r+\delta)L^*]}$.

pattern is reinforced. ii. If dispersion runs from the smaller country Foreign to Home, then: for $K < K^*$, relative stocks are equalized - via dispersion - before absolute stocks are - due to trade -, and dispersion changes direction. The result is again a stable comparative advantage pattern. For $K > K^*$, the absolute stocks are equalized before dispersion would change direction, and so a comparative advantage reversal may occur.[140]

The last implication deserves some further discussion, as it is a result that does not typically obtain in the models of trade with renewable resources. If Foreign begins to trade specialized in H (since $S^* > S$) and the resource disperses from the Foreign to the Home patch (since $\frac{S^*}{K^*} > \frac{S}{K}$) and in addition, the environment is 'richer' at Home ($K > K^*$), then the absolute stocks of the resources are equalized through trade before the relative stock are equalized through dispersion. As the resource continues to flow out of the Foreign patch and into the Home patch, S will become higher than S^* and in this two-country model the comparative advantage in H switches to Home. Then Foreign will export M and import H from Home. Moreover, this new pattern of specialization and trade is stable, corresponding to the inverse (in terms of countries) of the first case of Proposition 6 above. In what follows we will assume the pattern of specialization is stable, unless otherwise noted.

If there is a strong world demand for H, Foreign specializes in H and Home remains diversified. If there is a strong world demand for M, Home specializes in M and Foreign remains diversified. This stands in contrast with Brander and Taylor (1998), where the *only* pattern of specialization possible in the tow-country case was for the resource abundant country to specialize, and for the labour abundant country to remain diversified. Introducing space can expand the set of possible trade patterns. In our setting, specialization in M is, indeed, one of the options for the relatively labour abundant country (Home). Due to stock dispersion and the 'absorbtion' effect from the neighbour's increased harvesting, the reversal of relative productivities is less mechanic.

Under *specialized* trading, the determination of the international price can be done readily by evaluating world relative demand at the intersection with the vertical segment of the world relative supply in Figure 3.4. Therefore,

$$p = \frac{\beta}{1-\beta} \cdot \frac{L}{qS^*L^*}. \tag{3.21}$$

[140] Footnote 22 implies that there are cases where both $L > L^*$ and $K > K^*$ hold and Foreign still specializes in H.

What will be the level of the two stocks, given their interdependence? It turns out that the stocks are equivalent to those already determined above in (3.17) and (3.18), where dispersion reinforces the pattern of comparative advantage. The endogenous price level when the resource exporter is specialized can then be determined explicitly as:

$$p_{spec} = \frac{\beta}{1-\beta} \cdot \frac{L}{qK^* \left[1 - \frac{q(r+\delta)}{r(r+2\delta)} L^*\right] L^*},$$

which increases with the relative world taste for the resource good and the importer population, and decreases with determinants of resource abundance in the exporter country.

Suppose now the two trading partners have reached a *diversified* steady-state. Then the following holds:

Proposition 7: i. *In a diversified trading steady-state, wages and stocks will be equalized and there will be dispersion in the steady-state.* ii. *If $S_A < S_A^*$ or equivalently, if $p_A > p_A^*$ then Foreign will export H and Home will export M.*

To prove the first part of i., when the manufactured good is produced, prices are as in equation (3.4) above. A diversified equilibrium in both countries then necessarily imposes equality of stocks. This result parallels the Factor Price Equalization and Resource Stock Equalization results in Brander and Taylor (1998).[141] The second part of i. is guaranteed by the assumption of different carrying capacities and equal stocks, in which case positive net dispersion exists. The reason for ii. is obvious.

Turn now to the case of the country holding a comparative advantage in the resource good - here Foreign - being diversified in the steady state. When Foreign is diversified, the international price will mirror the autarkic relative price. In a steady-state equilibrium, we have then

$$p = \frac{1}{qS^*}. \tag{3.22}$$

Re-write relative world demand as $p = \frac{\beta}{(1-\beta)\left(\frac{H}{M}\right)}$ and calculate the relative quantity of H demanded in equilibrium as: $\left(\frac{H}{M}\right)^d = \frac{\beta}{1-\beta} qS^*$. This is represented in Figure 3.4 by the intersection between RD' and RS^*. This relative demand is met by the following relative supply, where the harvesting good comes exclusively from the Foreign country: $\left(\frac{H}{M}\right)^s = \frac{qS^* L_H^*}{L+L^*-L_H^*}$. Equating

[141] See Proposition 1, p. 189.

the two yields the optimal allocation of labour across sectors in diversified Foreign: $L^*_H = \beta(L + L^*)$. This of course needs to be strictly less than L^*, which is equivalent to $\frac{L^*}{L} > \frac{\beta}{1-\beta}$. Recalling that Foreign is the smaller country ($L^* < L$) for this specialization pattern to occur in the first place, this scenario is feasible as long as the taste for the resource good is relatively low, or $\beta < \frac{1}{2}$.

Harvesting in Foreign can be determined as $H^* = qS^*\beta(L+L^*)$. Imposing the Foreign stock equilibrium condition, together with re-writing (3.1) for Home at a steady-state with zero harvesting,[142] yields the relative equilibrium stocks as follows:[143]

$$\left(\frac{S}{K}\right)_{M/Foreign_D} = 1 - \frac{\delta q \beta}{r(r+2\delta)}(L + L^*) \tag{3.23}$$

and

$$\left(\frac{S}{K}\right)^*_{D/Home_M} = 1 - \frac{(r+\delta)q\beta}{r(r+2\delta)}(L + L^*). \tag{3.24}$$

Notice that the pattern of specialization is once again stable. Dispersion will flow from the Home patch and into the Foreign patch in equilibrium, since $\left(\frac{S}{K}\right)_{M/Foreign_D} > \left(\frac{S}{K}\right)^*_{D/Home_M}$. The endogenous price level can be determined from (3.2) as:

$$p_{div} = \frac{1}{qK^*\left[1 - \frac{(r+\delta)q\beta}{r(r+2\delta)}(L + L^*)\right]}. \tag{3.25}$$

Given this, we attempt to calculate the equivalent conditions of (3.19) and (3.20) describing the 'perverse' stock effects of trade for the case when Foreign is diversified. Appendix (6) shows, however, that such effects are not obtained in these circumstances: under diversified trading, it is not possible that the resource level increases in the net resource exporter and decreases in the net resource importer.

3.3.2 Conservation and Welfare Implications

The usual results in the literature concerning conservation are that the level of the resource falls in the resource exporter due to increased exploitation and rises in the resource importer, due to decreased harvesting pressure.

[142] just like we did in the specialized case above.
[143] See Appendix (5) for the derivation.

Specialization in the non-resource good has an implicit conservationist effect. In our framework with a mobile resource, these results will not hold in general. Moreover, the exact opposite results are possible. Being able to solve analytically allows for a series of simple but instructive exercises. Notice first, that in terms of stock levels, the results in the two-country case with full specialization are similar to the ones already presented in the two small open economies scenario above. The reason for this equivalence is that stock dynamics in the two patches are influenced by similar dispersion and harvesting patterns. When the two countries are each producing a single good, there will be full effort spent harvesting in one country, and zero effort in another, and the conservation results obtained in the previous section hold. What is different is, of course, the fact that the world price is now endogenous, which allows for a wider array of welfare effects, as the following paragraphs show. We consider sequentially the specialized and the diversified case.

Specialization in the resource good

When Foreign is specialized in the resource good and Home is specialized in the industrial good in a long-run trading equilibrium, there are four potential situations concerning the evolution of the two stocks: two in which the stocks have opposite dynamics, and two in which their dynamics concur. The long run trading steady-state stocks are compared to their autarky counterparts established in (3.7), (3.8). The graphical representations of the cases can be found in Appendix (8).

Case 1: Resource stock decreases in Home and increases in Foreign.

This situation actually cannot occur in practice, given our specifications. It would imply that both inequalities (3.19) and (3.20) hold at the same time, and this was shown above to be impossible.

Case 2: Resource stock increases in Home and decreases in Foreign.

This is the classical case in the literature. Algebraically it assumes the opposites of (3.19) and (3.20) to hold, and this happens for plausible parameter values. Since the international price is inversely related to the stock in Foreign[144], the long-run international price will be determined given the lower steady-state level of S^*, thus higher than the international price established when the countries start trading. In graphical terms, the Home PPF will rotate upwards having a higher vertical intercept, given the higher productivity in the resource good, as the international price line based in

[144] By equation (3.21).

the point of maximum manufacturing production on the horizontal axis will rotate downwards ($\frac{1}{p}$ decreases). Home thus gains in terms of both welfare and conservation in this case. On the other hand, Foreign PPF rotates downward, having a lower productivity in H given by the lower resource stock, while the international price line based in this intercept point rotates upward. Foreign will gain in welfare terms by trading (the terms of trade line and the PPF move in opposite directions, thus allowing the specialized exporter to reap the gains from trade), although will obviously lose in terms of conservation.

Case 3: Resource stock increases in both Home and Foreign.

This situation assumes that (3.20) and the opposite of (3.19) hold concomitantly.[145] Since this implies the ratio of the two countries populations $\frac{L^*}{L}$ be less than two different expressions, the case is possible. The international price will decrease compared to the start of trading, and the following conservation and welfare effects are incurred in the two countries. In Home, the PPF will pivot outwards, just like in the previous case, since Home is gaining in terms of conservation, while the price line will pivot outwards as well ($\frac{1}{p}$ increases), and the welfare gains for Home are the largest. Foreign's PPF also rotates upwards, as the price line based in the vertical intercept becomes steeper. The specialized resource exporter thus gains in terms of both conservation and welfare, although gains are relatively smaller due to reduced terms of trade.

Case 4: Resource stock decreases in both Home and Foreign.

This occurs when (3.19) holds, while the opposite of (3.20) is also true, or when $\frac{L^*}{L}$ is larger than two fractions in parameters r, β, δ.[146] In graphical terms, both the PPF and the trade line based in the horizontal intercept for the M-specialized Home are rotating downwards due to resource depletion and deterioration of the terms of trade, respectively. When the long-run price line falls below the autarkic PPF too, the specialized manufacturing exporter's initial gains from trade are eroded and it loses in the long run. For Foreign, the PPF rotates downward as well, yet the trade line based in the vertical axis becomes flatter: although losing from a conservation point of view, the H-specialized exporter gains again in welfare terms.

This last scenario yields a surprising result. While in the small open economy case the world price is given, so that specialization in M is unambiguously beneficial for Home, regardless of stock effects, here the specialized industrial exporter may lose from trade. The algebraic condition under

[145] Notice (3.20) is the more stringent requirement of the two.

[146] Notice (3.19) is now the more stringent requirement.

which his takes place is derived in Appendix (7) to be equivalent to:

$$\frac{\beta}{1-\beta} \cdot \frac{r+\delta}{\delta} < \frac{L^*}{L} < \frac{S_{A/Foreign_A}}{S^*_{H/Home_M}} \tag{3.26}$$

and this is plausible for a range of parameter values, when the taste for the harvesting good is 'not too strong'.

The effects can be summarized in the following table, where '+' means gain and '-' means loss for conservation (C) and welfare (W), while the arrows indicate the evolution of the resource stock in the two locations. It can be seen that, while the fourth column depicts a worst case scenario for Home, the third case seems to be a focal point for a potential policy cooperation between the neighbours.

		$S^*\uparrow, S\downarrow$	$S^*\downarrow, S\uparrow$	$S^*\uparrow, S\uparrow$	$S^*\downarrow, S\downarrow$
Home$_{(M)}$	C	.	+	+	-
	W	.	+	+	-/+
Foreign$_{(H)}$	C	.	-	+	-
	W	.	+	+	-/+

Figure 3.5: Conservation and welfare

Diversified production in Foreign

When Foreign is diversified, exporting H and Home is specialized in the production of M, there is only one case to look at, since it was argued in Appendix (6) and above that no 'perverse' stock effects can arise in equilibrium in this case. Therefore, the stock dynamics will be characterized by the fact that resource becomes less abundant in Foreign, and more abundant in Home. Notice also that if Foreign starts trading specialized in H, the decrease in stock rotates the PPF downwards, while increased scarcity in the exporter pushes the world price up. Thus, in a graph like the one in Appendix (8), Figure 3.6, the two lines rotate in the same direction, and cannot become coincidental through trade. Thus, the only possibility is for Foreign to start trading diversified and in the long run to also be trading while diversified. The international price when the countries open to trade needs to be $p^w = \frac{1}{S^*_A}$, while the international price in the long-run is higher:

$p^w_{ss} = \frac{1}{S^*_{D/Home_M}}$, where the expressions for the two stock levels in Foreign are given in (3.16) and (3.4), respectively. It can be clearly seen that Home benefits in terms of both conservation and welfare effects, while Foreign loses in terms of both in spite of the beneficial terms of trade effect, due to the shrinking of the consumption possibilities frontier.

Like in the small open economy section and in the specialized trading Case 2 above, there is a possibility that the manufacturing goods exporter, Home, becomes diversified in the long-run: productivity in H improves, while the price of H increases. There is even a possibility that comparative advantage switches between the two countries. When Foreign is specialized in H, and stock increases in Home and decreases in Foreign, Home may become diversified if the slope of the PPF increases enough to equal the depressed $\frac{1}{p^w}$, or: $qS_{M/Foreign_H} = \frac{1-\beta}{\beta}\frac{qL^*S^*_{H/Home_M}}{L}$, which is equivalent to: $\frac{L^*}{L} < \frac{\beta}{1-\beta} \cdot \frac{K}{K^*} \cdot \frac{r(r+2\delta)-\delta\beta q(L+L^*)}{r(r+2\delta)-(r+\delta)q\beta(L+L^*)}$ and (3.19) holds.

Accounting for the spatial dispersion of the resource generates some intriguing effects, that run contrary to the conventional notion that free trade necessarily exacerbates the tragedy of the commons. This is attributable to the extra compensation effect for the stock exploited more with trade and the 'natural' decrease in numbers by migration of the stock that increases too much relative to the carrying capacity of the patch.[147] This implicit free riding is likely to have implications for policy cooperation between neighbours.

It is perhaps important to note that, while the two cases above provide examples of the ways in which spatial mobility of the resource can change the typical literature results, the latter ones are also obtainable in our spatially-explicit framework. Obviously, for values of parameters that satisfy conditions complementary to the ones above, Home and Foreign stocks evolve in more predictable directions: the resource may decrease in abundance with trade in Foreign and increase in abundance at Home, while dispersion either does not change directions, or is insufficient to cause a comparative advantage reversal.

Quantitatively, given the expressions above, demands and indirect utility functions can be calculated in the two scenarios, with Home specialized in the manufacturing good and Foreign either specialized in the harvesting good or diversified. These calculations imply a relatively high amount of algebra and the method is illustrated in Appendix (9). By comparing

[147] In this framework fish 'vote with their fins' when confronted with a new resource management or specialization pattern that is 'too conservationist,' so that congestion considerations kick in.

the autarkic and trading indirect utilities it is relatively straightforward to derive conditions on parameters for which the resource abundant country gains in welfare terms, while the country specializing in the manufacturing good loses. Alternatively, these conditions can be derived by comparing the slopes of the production possibilities frontiers and the international price in the various configurations.

3.4 Resource Policy

As seen above, there is a rich array of possible strategic interactions between the two countries when resource policy is involved. An exhaustive discussion of the introduction of resource management in this framework exceeds the space constraints here and constitute the object of future study. Here we present briefly a few questions that can be asked. What are the incentives for adopting some form of resource management? Could high standards/good resource management be contagious when the resource is mobile between two jurisdictions, or are free riding incentives even stronger, leading to a race to the bottom? The answer to the first question can be intuitively understood based on the preceding analysis. Reformulate the question as follows: can free riding on the neighbor's resource management actually make one worse off, thereby prompting one to respond by also adopting some form of management of the open-access resource? Based on the above discussion, there is one case in which this is indeed a possibility. Such a scenario would involve the following. Relax the open-access to the resource assumption for Foreign. Assume that there is restricted entry into the H^* sector, hence active firms make positive profits amounting to $(pqS - w)L_H^*$, which are then redistributed by the government. Due to dispersion, part of the Foreign rent is passed on to the diversified Home via an increased level of the resource stock. The key difference between Home and Foreign when the latter implements a resource management policy is the following: in Foreign, resource rents are appropriated by the government and redistributed back to the consumer, thus there is no excessive entry. In Home, rents generated by Foreign resource conservation policy are appropriated by firms in sector H, determining rent dissipation via increased entry and may determine that the initially diversified Home begins to export the resource good in equilibrium. It may then lose in the long run, following Brander and Taylor (1997). Thus, resource policy adoption by one country may influence the specialization pattern of its neighbour and induce particular welfare effects. This is in sharp contrast to the common-pool resource scenario analyzed by Bulte and

Damania (2005), where the two countries' harvesting behavior is mutually orthogonal in autarky.[148]

We turn in what follows to the issue of incentives for unilateral resource management adoption when the resource mobility is characterized by relative density-dependent dispersion between the two jurisdictions. Assume for now that Foreign is in autarky and that it adopts a resource management program in the form of output taxation in the resource sector.[149] Firm profits in the H sector are now $\pi_H = (p-\tau)H - wL_H$, while profits in manufacturing are $\pi_M = M - wL_M$. With free entry, the unitary wage in this economy is again pinned down from the manufacturing sector. Substituting $w = 1$ and the harvesting production function $H = qSL_H$ in the free entry condition for the H sector we obtain the expression of the fully rent-extracting output tax as: $\tau = p - \frac{1}{qS}$.[150] Total resource rent extracted by the output tax is thus $R = \tau H = \tau qSL_H = (pqS-1)L_H$. This is then redistributed back to consumers, altering the budget condition for the representative consumer. The optimization problem becomes:

$$\underset{H,M}{Max} \quad U = H^{\beta}M^{1-\beta},$$

subject to $pH + M = w + (pqS-1)\frac{L_H}{L}$.

The individual demands are: $H = \frac{\beta}{p}[w + (pqS-1)\frac{L_H}{L}]$ and $M = (1-\beta)[w + (pqS-1)\frac{L_H}{L}]$ and the market clearing conditions in the goods and labour markets imply:

$$\begin{aligned} H \cdot L &= qSL_H \\ M \cdot L &= L_M \\ L_H + L_M &= L. \end{aligned}$$

Substituting in the demands and solving yields the following optimal labour allocation between the sectors: $L_H = \frac{L}{1+pqS\frac{1-\beta}{\beta}}$, $L_M = \frac{L}{1+\frac{\beta}{1-\beta}\frac{1}{pqS}}$. Since $p = \tau + \frac{1}{qS}$, these can be re-written as: $L_H = \frac{\beta L}{(1-\beta)\tau qS+1}$ and $L_M = \frac{(1-\beta)(\tau qS+1)}{(1-\beta)\tau qS+1}$. As expected, when preferences for the resource good are stronger (higher β), the share of labour allocated to harvesting increases. Also, when the resource is more abundant (higher S), less labour is needed

[148] E.g. see p. 888.

[149] For notation simplicity, we abstract in what follows from inserting the star, when all expressions refer to Foreign.

[150] If an equivalent effort tax is imposed instead, $\pi_H = pH + (w+\tau)L_H$ and then $p = \frac{1+\tau}{qS}$, and the result is similar.

to satisfy the demand for H in autarky. Aggregate demands are then calculated as: $H = \frac{qSL}{1+pqS(\frac{1-\beta}{\beta})}$ and $M = \frac{1}{1+\frac{1}{pqS}(\frac{\beta}{1-\beta})}$ and can be re-written as: $H = \frac{\beta qSL}{(1-\beta)\tau qS+1}$ and $M = \frac{(1-\beta)(\tau qS+1)L}{(1-\beta)\tau qS+1}$, respectively.

While it can be easily noticed that for an output tax equal to zero (i.e. no resource management) the aggregate demands take the form presented in section 2.1 above, for any positive tax, demands are lower, given the same level of the resource stock. What changes as a result of implementing the conservation program is of course the level of the resource stock. This can be easily seen in a graph like the one in Appendix (10). In the absence of resource dispersion, or when dispersion is very weak (δ low) resource stock improves unambiguously after the imposition of the tax. Therefore there is significant scope for welfare gains due to unilateral policy, arising from the improved level of the resource. With dispersion (or for δ high), and in the absence of a symmetrical resource policy in the neighbouring Home, a unilateral resource management adopted in Foreign leads to a situation where under autarky, stock level increases - and implicitly welfare gains - can be substantially diluted by free-riding.

The adoption by Foreign of a resource management policy aimed at conserving the stock in order to maintain productivity in H at a high level is bound to be weakened by free-riding even in the small open economy case. Conservation efforts in the foreign country will grant a resource-specialized Home an even stronger comparative advantage in H, by increasing its absolute stock level via dispersion, and allowing it to have a more lax policy or none whatsoever. Thus, it can be inferred that eventual resource policies are *strategic substitutes* with a mobile resource. This result differs from that obtained in Bulte and Damania (2005), when they assume the countries are jointly exploiting the same resource stock and there is no resource mobility.[151] The reason for this difference has to do with the fact that the separation of the exploitation of the two stocks changes the nature of the strategic interactions from the case where the stock is jointly exploited, by allowing for additional free riding as the overexploitation of the domestic patch triggers resource inflows from the neighbouring patch. Density-dependent dispersion allows a country to escape, at least partially, the stock externality of own harvesting. This own-stock externality can be compensated for by the attracted dispersion in this model.

With trade, the incentives to unilaterally adopt a form of resource management improve. We do not repeat the algebraic calculations for this case,

[151] In their model resource policies are strategic complements in the small open economy case and strategic substitutes in autarky or in the two-country model.

but the qualitative implications are simple. If the 'conservationist' country is the one exporting the resource good in equilibrium, while its neighbour is specialized in manufacturing, the free-riding is much diminished. In other words, the incentives to adopt a form of resource management in the country that exploits the resource most is stronger with trade.[152] While in autarky, resource free riding implies that there are strong arguments for a sort of inter-jurisdictional policy cooperation between the two neighbours, under free trade and specialization according to the respective comparative advantages, the coordination requirements are less onerous: even unilateral policy can be successful.

3.5 Conclusion

Spatial economic modeling is increasingly recognized as an important new direction of study, particularly with respect to the management of renewable resources such as fisheries. While belonging to the broader effort to answer whether trade is good or bad for the natural environment, this paper is an attempt to explore the impact of accounting for resource mobility on the effects of trade between neighbours. In particular, the model features density-dependent dispersion between two adjacent regions under different international jurisdictions and looks at the impact on 'conservation' and 'welfare', represented by the indirect utility function of the representative consumer.

There is a general argument to be made that well-grounded resource management of renewable resources has to be be spatially explicit. More specifically, this paper discusses the implications of the resource interconectedness of the two neighbouring economies, that can have important consequences both in autarky and trade. This is in part achieved by pointing to the fact that traditional results based on homogeneously distributed resources may not hold, and policy-making dealing with such interactions as above should acknowledge the differences. When the resource is mobile and disperses according to relative congestion, some findings in the literature are changed, some are maintained, and new results are also possible. In particular, trade may make the manufacturing-specialized country lose resource stock and lose in terms of welfare. It may also lead the harvesting-good specialized country to gain in terms of resource stock and gain also in terms of welfare via a strong 'resource absorption/capturing' effect that has an

[152] This can be regarded as a 'double dividend' of trade liberalization in this particular scenario.

indirect impact on productivity in the harvesting sector. While under diversified trading, the existing literature results are quite robust, endogenous comparative advantage creation, comparative advantage reversal and perverse resource stock effects are possible. The additional level of linkages induced by resource mobility can have important policy consequences. While resource management can be 'contagious' when the resource is mobile, trade makes unilateral adoption more likely under certain specialization patterns.

APPENDIX:

(1). This section discusses two closely-related specifications for the density-dependent dispersion process.

Option I: Dispersion is a simple function of the relative population densities in the two patches.

$$\text{Dispersion} : D(S, S^*) = \delta(\frac{S^*}{K^*} - \frac{S}{K}).$$

However, adopting it presents a challenge for the tractability of the model: in the typical bioeconomic equilibrium model including the logistic growth function and the Schäffer harvesting it is difficult to get any closed form results.

Option II: Inward dispersion is proportional to the stock level, while the direction of migration continues to be given by relative stock densities.

$$\text{Dispersion} : D(S, S^*) = \delta S(\frac{S^*}{K^*} - \frac{S}{K}).$$

This specification has the advantage of tractability, yet it should be noted that it does contain one extra "feature": $\frac{dD}{dS^*} = \delta \frac{S}{K^*}$ or the dispersion-induced effect of the foreign stock on the home stock is proportional to the latter.

This can be justified relying on what biologists term an *Allee effect*, or a positive correlation between population density and growth rate[153], which is a general feature that has gained prominence in studies concerning the viability of animal populations. The effect is likely to arise in due to the following circumstances:

- Adults provide protection for larvae or young fish, and so a larger existing stock of adults may encourage inward dispersion (e.g. sea urchin).
- A species alters the environment it inhabits so as to facilitate own growth, reproduction, and this may encourage immigration (e.g. hemlock).
- Any form of inter-species competition implies a type of an Allee effect, due to the favourable effects that 'less of the other' and implicitly 'more of us' has on immigration.

[153] Allee et al. 1949, the effect originally meant decreased cooperation at low densities in a population.

Besides, this specification also corresponds to the spirit of the advection-diffusion models for biodiffusion, whereby the movement of the members of a certain population is influenced by "...an attractive force, which induces directed movement of animals toward favourable environments; and...population pressure due to interference between individual animals."[154] This description corresponds loosely to our simplified formulation of dispersion, which increases with the stock density differences between locations and also with the stock of already existing resource in the source/target patch.

Therefore, the Allee effect and the biological processes characterized by advection-diffusion could, by themselves motivate the adoption of the 'algebraically-friendlier specification.' Yet, it can also be shown that, while quantitatively different, there is little qualitative change in the nature of our results when using the more general specification of Option I.

An additional issue is that what leaves one patch does not necessarily arrive entirely in the other patch. Dispersions do not add-up due to the fact that there is a loss of migratory stock: $D + D^* = d$, where d represents mortality during the trip. It can be expected that d is more significant, the more remote the two patches are from each other.

It should be noted that the specification of the bioeconomic model is obviously too stylized to correspond closely to any species/environment in particular. Hence, conclusions are not to be directly applied to any specific management program. However, the basic nature of the interactions between the spatial movement of stock and harvesting is likely to 'travel.'

The following sections present the derivations for the various results in the paper:

(2). Small open economy: Home specialized in H, Foreign autarkic:

The two steady-state stock levels can be determined as follows:

A specialized equilibrium will entail $H = qSL$ at Home, thus the relative stock will be determined from (3.5) as:

$(\frac{S}{K})_H = \frac{1}{r+\delta}(r + \delta\frac{S^*}{K^*} - qL)$, while in Foreign:

$(\frac{S}{K})^*_A = \frac{1}{r+\delta}(r + \delta\frac{S}{K} - q\beta L^*)$.

Substituting between the two equations we obtain relations (3.11) and (3.12) in the text.

[154] See Akira Okubo and Daniel Grünbaum, 'Mathematical Treatment of Biological Diffusion', chapter 5 in Okubo and Levin, Diffusion and Ecological Problems, p. 158.

(3). Small open economy: Home specialized in M, Foreign autarkic:

Substituting zero harvesting and imposing the steady-state condition in the growth equation for the Home, one gets the relative stock level at Home as:

$(\frac{S}{K})_M = \frac{1}{r+\delta}[r + \delta(\frac{S}{K})^*]$, while the relative stock in autarkic Foreign is:

$(\frac{S}{K})^*_A = \frac{1}{r+\delta}[r + \delta\frac{S}{K} - q\beta L^*]$.

From these two equations one finds expressions (3.15) and (3.16) in the text.

(4). Small open economies: Home specialized in M, Foreign specialized in H:

There will be zero domestic harvesting at Home and full harvesting effort in the Foreign. The relationship between the two stocks will then be given by:

$(\frac{S}{K})_M = \frac{1}{r+\delta}(r + \delta(\frac{S}{K})^*)$ and

$(\frac{S}{K})^*_H = \frac{1}{r+\delta}(r - qL^* + \delta\frac{S}{K})$. Putting the two together we obtain expressions (3.17) and (3.18).

(5). Two-country case: Home specialized in M, Foreign diversified:

Given zero harvesting at Home and harvesting in Foreign given by: $H^* = qS^*\beta(L + L^*)$, we can use the resource stock growth relations to derive the following two equations linking the relative resource abundance in the two patches:

$(r + \delta)\frac{S}{K} = r + \delta\frac{S^*}{K^*}$

and

$(r + \delta)\frac{S^*}{K^*} = r + \delta\frac{S}{K} - q\beta(L + L^*)$. Solve these to get expressions (3.3) and (3.4).

(6). Two-country case. Resource stock at Home, specialized in M, while Foreign is diversified is less than under autarky (in both countries) if:

$\left(\frac{S}{K}\right)_{M/Foreign_D} < \left(\frac{S}{K}\right)_{A/Foreign_A}$

is equivalent to:

$1 - \frac{\delta q\beta}{r(r+2\delta)}(L + L^*) < 1 - \frac{\beta q}{r(r+2\delta)}[(r + \delta)L + \delta L^*]$, which is never satisfied.

Under the same conditions, resource stock in Foreign is higher than under autarky if:

$\left(\frac{S}{K}\right)^*_{D/Home_M} > \left(\frac{S}{K}\right)^*_{A/Home_A}$

is equivalent to:

$1 - \frac{(r+\delta)q\beta}{r(r+2\delta)}(L + L^*) > 1 - \frac{q\beta}{r(r+2\delta)}[\delta L + (r + \delta)L^*]$, which is also never satisfied.

(7). This section derives the condition for the negative welfare effect in Home to obtain in Case 4, namely, when both S and S^* decrease and the international relative price of the resource good increases. As explained in the text, Home also loses in welfare terms when the long run trade line lies within the autarkic production possibilities set, i.e. when $\frac{1}{p^w}$ < slope of autarkic PPF, or
$\frac{1}{p^w} = \frac{q(1-\beta)L^* S^*_{H/Home_M}}{\beta L} < qS_A$ and in addition, (3.19) holds. The two conditions can be concomitantly satisfied if the following condition on parameters is true: $\frac{r+\delta}{\delta} < \frac{K\left(1-\frac{q\beta[\delta L+(r+\delta)L^*]}{r(r+2\delta)}\right)}{K^*\left(1-\frac{q(r+\delta)L^*}{r(r+2\delta)}\right)}$, which simplifies to:

$$\beta < \frac{r(r+2\delta) + \frac{K^*}{K} \cdot \frac{r+\delta}{\delta}[q(r+\delta)L^* - r(r+2\delta)]}{q[\delta L + (r+\delta)L^*]},$$

requiring the taste for the resource good to be 'not too large'.

(8). The cases depicted in Figures 2.6 through 2.8 below pertain the two-country setting, when Home trades specialized in M and Foreign is specialized in H.

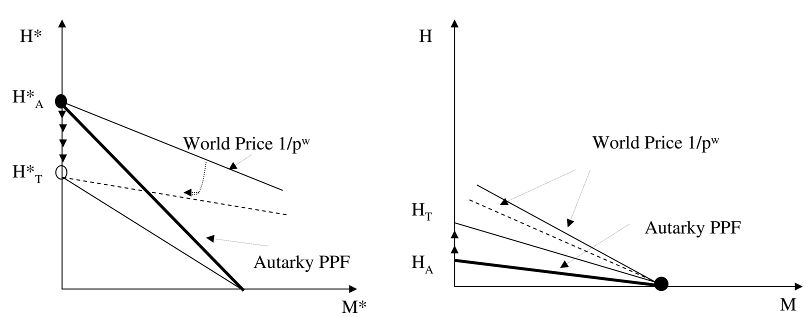


Figure 3.6: Case 2: S^* decreases, S increases

(9). Using the autarkic and trading stock levels derived in the paper, the autarkic indirect utility function at Home is:

$$V_A = [q\beta LK \cdot (1 - \frac{q\beta}{r(r+2\delta)}[(r+\delta)L + \delta L^*])]^{\beta}[(1-\beta)L]^{1-\beta},$$

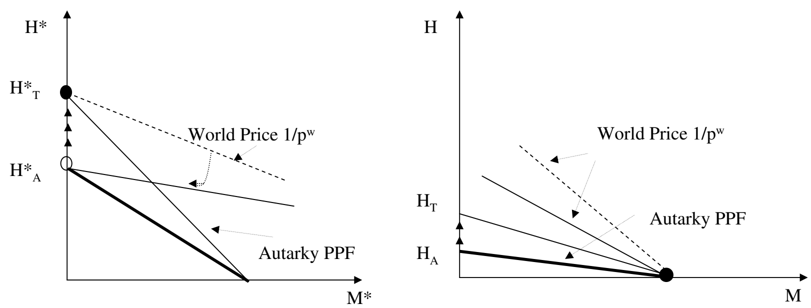


Figure 3.7: Case 3: S^* increases, S increases

and symmetrically for Foreign.

With trade and Foreign specialized in H, Home's indirect utility becomes:

$$V_{Ts} = [(1-\beta)qL^*K^*(1-\frac{qL^*(r+\delta)}{r(r+2\delta)})]^{\beta}[(1-\beta)L]^{1-\beta},$$

while Foreign indirect utility function is now:

$$V_{Ts}^* = [\beta qL^*K^*(1-\frac{qL^*(r+\delta)}{r(r+2\delta)})]^{\beta}[\beta L]^{1-\beta}.$$

With trade and Foreign diversified, the respective indirect utility functions for Home and Foreign are:

$$V_{Td} = [\frac{[(1+\beta)L+(1-\beta)L^*]qLK^*}{L+L^*}(1-\frac{(r+\delta)q[(1+\beta)L+(1-\beta)L^*]}{r(r+2\delta)})]^{\beta}[(1-\beta)L]^{1-\beta}$$

and

$$V_{Td}^* = [\frac{[(1+\beta)L+(1-\beta)L^*]qL^*K^*}{L+L^*}(1-\frac{(r+\delta)q[(1+\beta)L+(1-\beta)L^*]}{r(r+2\delta)})]^{\beta}[(1-\beta)L^*]^{1-\beta}$$

Comparing the pre and after trade indirect utilities, it is possible to derive exact conditions on parameters that are necessary for the various welfare cases discussed in the paper.

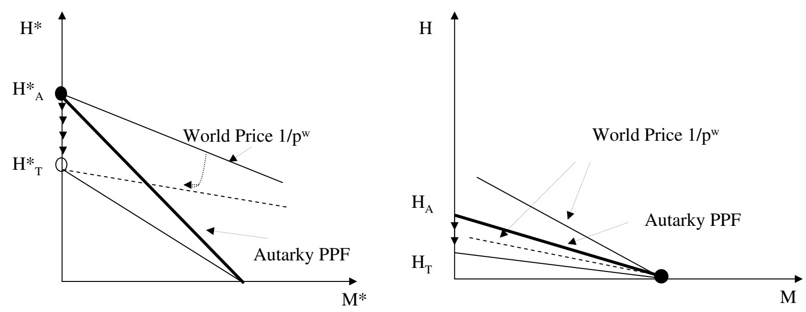


Figure 3.8: Case 4: S^* decreases, S decreases

(10). Under a resource management program in autarky, harvesting can be written as: $H^{policy} = \frac{qSL\beta}{(1-\beta)\tau qS+1}$, which is clearly less than the amount of harvesting done in the absence of policy: $H = qSL\beta$. The resource stock is thus larger with policy, as can be seen in the following graph, where we abstract from dispersion and the equilibrium stock level is given by the intersection between the harvesting and resource growth functions in Figure 3.9 below.

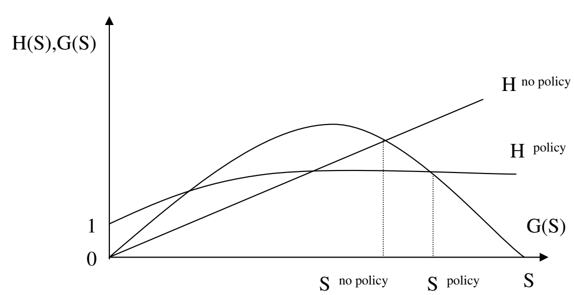


Figure 3.9: Effects of policy without dispersion

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Chapter 4

Renewable Resources, Pollution and Trade in a Small Open Economy

4.1 Introduction

Around the world, mostly in developing countries, but by no means limited to them, open-access fishing areas are often located in the proximity of polluting manufacturing facilities. According to a recent UN study, up to 80% of the ocean pollution is derived from industrial or residential land-based activities, in the form of 'excess nutrients (fertilizers, sewage, other nitrogenous compounds), persistent organic pollutants (POPs) (halogenated hydrocarbons, PCBs, and dioxins), radioactive substances'.[155] High profile examples of pollution-resource interaction issues range from the North Atlantic salmon fishery,[156] to the lobster fishery in the North Pacific, the collapsed walleye fishery in the Tittabawassee River in Michigan, the Baia Mare, Romania cyanide pollution of the rivers adjacent to gold mines and countless, little publicized local problems in the less-developed world. As the more biology-oriented literature documents, for many species of fish, the nursery grounds are located in the coastal areas, which are also the more polluted ones, due to the toxic waste spilled directly into the sea, or carried by rivers from inland. Due in part to poor regulation of the environment, many developing countries experienced an accelerated depletion of their resources after opening up to international trade. The welfare effects of this form of tragedy of the commons amplified by trade are likely to be quite significant in poor, small, developing economies, where the resource sector has an important share both in exports and GDP. At the same time, the phenomenon of dirty-industry migration from North to South - as a foresee-

[155] See Sale et al. (2008), p. 16.

[156] Among the chief causes cited as contributing to the collapse of North Atlantic fisheries were pollution and over-harvesting.

able effect of tightening up of standards in the developed world - may result in increased industrial pollution of the environment. Openness makes both scenarios theoretically plausible.

Renewable resources can be under two types of pressures: excessive harvesting, especially where there is no effective management, and pollution from other sectors. Previous work has looked at each of these pressures individually. Brander and Taylor (1997) show that a small open economy that exports an open access resource will suffer resource depletion and may incur a long run real income loss, whereas a country that exports the alternative non-resource good will gain from trade, because pressure is taken off the resource. Copeland and Taylor (1999) show that with a cross-sectoral pollution externality, trade tends to cause small countries to specialize. Severe resource depletion may occur. Also, in their model, a resource exporting country will gain from trade because it leads to a contraction of the polluting sector. However, many renewable resources are in reality concomitantly subject to *both* types of pressures.

The literature documents many instances of habitat quality influencing population levels, harvesting, and having detrimental welfare effects. For instance, several examples are provided in Knowler (2002), in a review of bioeconomic models employed to estimate the welfare effects of environmental quality.[157] The interaction between pollution and international trade has been extensively studied recently. The approach used in the book by Copeland and Taylor (2003) is to build a unified general equilibrium framework which allows them to clearly identify the various effects characterizing the interaction and to take into account the endogenous nature of environmental policy. Yet, as they acknowledge, for poor resource exporters, the evolution of the stock of natural resources with trade is likely to be more important than pollution for their welfare (Copeland and Taylor (2003), p. 362). The manufacturing sector is generally under-developed and so the effects of additional local pollution on the consumers are likely to be low. Then, a key mechanism identified by the authors as influencing the level of pollution with trade: namely the endogenous policy response - may not play as important a role.[158] However, the existence of a polluting sector and its

[157] Some examples provided in Knowler (2002) include: the effect of changes in water salinity on shrimp catch in Pamlico Sound, North Carolina (Swallow (1994)), the impact of increased nutrient and sediment loads on aquatic vegetation in Chesapeake Bay (Kahn and Kemp 1985), the effect of increased nutrient concentration on the Black Sea anchovy fishery in Knowler and Barbier (2001). Even closer to the spirit of this paper, Loomis (1998) analyze the effect of logging on the downstream fisheries in the form of sediments and water temperature changes.

[158] Another reason may be that the democratic channels by which higher pollution

external effects cannot be dismissed even in these economies. Some would argue it is likely to become even more of a problem, as production in the North moves towards cleaner, service-based sectors while the South gets a higher share of world's manufacturing.

Relying on the motivating examples discussed above, the basic question addressed in this paper is: what is the effect of trade when an un-managed renewable resource is subject to the two interacting problems: overharvesting and pollution? The present work builds on the baseline Brander and Taylor (1997) model and the subsequent Brander and Taylor (1998) and resembles the two in the fact that it deals with an open-access natural resource and the impact of international trade on its stock. It departs from the original Brander and Taylor framework in that it also assumes the existence of production externalities, as in Copeland and Taylor (1999). However, unlike the latter model, where the production in the clean sector is only a function of the "environmental capital" stock,[159] in the present paper the production of the "clean" good also depletes the stock of the resource. It is argued that the fact that *both* sectors exert a differentiated pressure on the stock of the resource proves to be important in establishing the results.[160]

To briefly preview the findings, the autarkic equilibrium in this economy is inefficient. Besides the open access problem, whose magnitude is a function of demand parameters, there is the uninternalized effect of pollution. However, opening up to trade allows the economy to potentially do better in the long run. Non-traditional gains from trade occur from spatially separating the conflicting sectors by focusing production on the area of comparative advantage. It is argued that - under certain conditions - specialization in the "dirty" good can be detrimental, while specialization in the resource good can be welfare-improving.[161] The policy relevance of the paper may be framed in terms of the industrial planning challenges faced by a small resource-endowed developing economy that eventually becomes open to trade. Even when disutility costs to consumers are small, excessive industrialization imposes external costs via the environment-based sectors.

triggers a policy response may not be functioning properly.

[159] i.e. cleanliness of a river, soil and there is no harvesting of the renewable resource per se.

[160] Thinking about other real-life examples: if sector H is tourism and sector M is a polluting manufacture, it is likely that both activities pollute the adjacent lake or river, although conceivably, to quite different degrees. Alternatively, given the wide evidence documenting the damaging effect of aquaculture for the environment, M can be thought of as fish or shrimp farming, while H is the harvesting of the wild resource.

[161] In a stylized way, this result runs contrary to the so-called Dutch Disease "symptoms" of the "Natural Resources Curse".

The analysis of welfare changes can give an indication as to what drives the results and will possibly suggest a direction for policy measures. If the only commodity traded once the economy opens up to trade is the manufacturing good, then spatial separation will likely reduce the stress on the resource and may bring welfare gains, provided that the country in question starts importing the industrial good. If the resource-based product (e.g. fish) is also tradable,[162] then overdepletion makes the results ambiguous, and several cases may develop, based on the parameters of the system. The two externalities here have partially offsetting effects, which in autarchy could bring the economy closer to a first best optimum than in the simple over-harvesting fishery model. As can be expected, opening up to trade alters these effects. Whether the country stays diversified or completely specializes in one of the sectors will play a role in deciding the welfare gains or losses from trade, as will the relative impact of the two sectors on the stock of the resource. Here the economy can in fact specialize in any of the sectors, and trade can bring a welfare improvement or a welfare decline. Increasing production in the relatively more harmful sector will have the effect of decreasing the stock below the autarkic steady state level, while (even incompletely) specializing in the relatively environmentally-friendly sector will raise the stock above it, likely influencing in turn the comparative advantage of the country.

There are not many studies focusing explicitly on the issue of renewable resources management with pollution. However, a few papers deal with related issues. Knowler, Barbier and Strand (2002) look at the effect on the stock of a resource of nutrient concentration increase of water. However, the polluting factor is exogenous and there is no trade-off between the resource sector and the polluting sector, which is captured in our model. McConnell and Strand (1989) analyze water quality impact on commercial fishing when consumer perception of better water quality shifts demand, while the supply of fish increases as well with water quality. Here the open-access dimension is missing, and the focus is domestic. A special issue of *Environmental Resource Economics* dedicated to the Economics of Non-convex Ecosystems[163] contains papers that specifically deal with existence of competitive equilibria, multiple basins of attraction, threshold and positive feedback effects and the local aspect of many environmental externalities. The closest to

[162] And this is the less restrictive, more realistic case.

[163] ERE (December 2003, Volume 26 Issue 4), with papers from: Dasgupta and Mäler, Chave and Levin, Scholes, Brock and Starrett, Mäler, Xepapadeas, and de Zeeuw, Crepin, Arrow, Dasgupta and Mäler, which are concerned with topics such as the economics of savannas, pollution in shallow lakes, multiple species forests and sustainable development.

this work is a relatively recent paper by Smulders, van Soest and Withagen (2004) which focuses on habitat destruction by having a specific factors model with three sectors, two of which are dependent on 'land' as a resource base or factor of production. While the paper is similar in the sense that their model also includes both 'within-industry' and 'between industry' externalities, the driving force of their results is the interplay between the negative long-run stock effects and the positive short-run search costs-reducing effect of a shrinking habitat size. Their work also reverses some of the results in Brander and Taylor papers, yet the model only applies to terrestrial resources, where habitat size can be increased or decreased by the expansion of agriculture.[164] In the present paper, inter-industry externalities are exclusively negative: pollution reduces the stock size, diminishing productivity in the harvesting sector, and it also increases the implicit search costs, as sparsely distributed marine resources are harder to catch. To the best knowledge of the author, the exact focus of this paper, who better fits the pollution-marine resources motivating examples, has not been previously undertaken.

The rest of the paper is organized as follows. The next section analyzes the autarkic general equilibrium in the short run and then in the long run, introducing the non-convexity issue. The third section then looks at the open economy equilibrium, analyzing possible specialization avenues and their impact on the stock of the resource and on welfare. The last section concludes and points to possible future research directions.

4.2 The Autarkic Model

Let the stock of the renewable resource S grow according to a natural growth rate G(S), like in the original Gordon-Schäfer model.

$$\frac{dS}{dt} = G(S(t)) - H(t) - Z(t) \tag{4.1}$$

where H is the harvest level and Z is the detrimental effect of pollution on the resource growth and where we take the stock S to follow a logistic growth function that was shown to perform quite well empirically for some species

[164] For marine resources it is difficult to imagine activities that physically diminish the habitat.

of fish:[165]

$$G(S) = rS\left(1 - \frac{S}{K}\right)$$

where r, the intrinsic growth rate of the resource and K, the carrying capacity are known parameters.[166]

It can be seen from equation (4.1) that activity in both sectors of the economy influence the change of stock.[167] As shown in the original fishery model, under open access, extraction will occur at zero profit levels, due to free entry into the sector that has the effect of driving rents to zero. The added complication here is the negative externality imposed by the polluting sector.

4.2.1 Supply

There are two productive sectors in this economy: harvesting of the renewable natural resource (H) and manufacturing (M). Both sectors are using one primary input: labour (L). In addition, production of H also depends on the stock of the resource according to a typical Schäfer yield function:

$$H = qSL_H, \tag{4.2}$$

while manufacturers use only labour and produce according to a very simple constant returns production function:

$$M = L_M. \tag{4.3}$$

However, this is a polluting activity. Pollution (Z) is generated at rate alpha in the process, so that

$$Z = \alpha M = \alpha L_M.$$

[165] Brander and Taylor (1997) list Pearl (1930) and Feller (1940) for empirical support of the logistic form of growth and Paterson and Wilen (1977) for empirical support of the choice of harvesting production function. See Brander and Taylor (1997), p. 531-532.

[166] Jinji endogenizes the carrying capacity. In his forestry model K depends linearly on the stock of the "base resource:" land. A number of comparative statics exercises can be performed when K is allowed to vary. See Jinji (2007), p. 796.

[167] For the sake of accuracy, due to the multiplicity of biological/natural and anthropogenic interactions existent in a marine environment, there is little conclusive evidence to date that 'normal' pollution actually kills fish, except for 'ecological disasters.' However, scientific evidence that pollution leads to perturbations in the reproducing system of fish is available. Thus, the effect of the pollution externality on the stock of fish could also enter in a more complicated manner than here, namely via an intrinsic growth function r(Z) that is decreasing in pollution: dr/dZ<0. Yet, our specification is equivalent to one in which the 'true' intrinsic growth rate ρ is diminished by a properly-weighted pollution effect to yield the 'actual' intrinsic growth rate r as follows: $r = [\rho - \frac{Z}{S}(1 - \frac{S}{K})^{-1}]$.

Assume pollution does not accumulate[168], there is no abatement and no pollution policy[169] and emissions intensity α is given.

Let M be the numeraire commodity and so $p_M = 1$. From the zero-profit condition in the manufacturing sector: $\Pi^M = M - wL_M = 0$ we obtain that $w = 1$. Because L is the only factor firms in the harvesting industry have to pay for under open access, profits will be:

$$\Pi^H = pH - wL_H = pqSL_H - wL_H$$

and the free entry/zero profit condition implies:

$$w = pqS \Rightarrow p = \frac{1}{qS}. \tag{4.4}$$

Therefore, if both sectors of the economy are active in autarky, the relative price of the harvesting good is determined by the stock level. This autarkic price increases as the resource becomes more scarce and decreases if the harvesting productivity improves.

4.2.2 Demand

On the demand side, there is a representative consumer with preferences described by a Cobb-Douglas utility function including both goods, and with (1-β) the share of M, β the share of H in total spending.[170] In the first best equilibrium there would be resource rents. However, in our open-access framework, rents are dissipated and the only income accruing to the consumer is the wage. The consumer supplies inelastically one unit of labour and solves:

$$\underset{H,M}{Max} \;\; U = H^{\beta} M^{1-\beta} \; s.t. \; pH + M = w.$$

[168] Pollution just flows downstream if the pollutant and the clean sector are located along a river. Treating pollution as a stock might be more appropriate for lakes. This scenario is omitted here for simplicity.

[169] there is no regulation that internalizes any of the two externalities: open-access or pollution.

[170] The focus on production externalities developed here is particularly applicable to developing resources-based economies: their environments are still relatively pristine and the health consequences of industrial pollution may not be as severe, thereby making the assumption of no consumer-disutility of pollution more credible. Also, an endogenous policy response mechanism may not work, due to the fact that environmental-groups pressure is weak and/or the countries' democratic channels are not functioning properly.

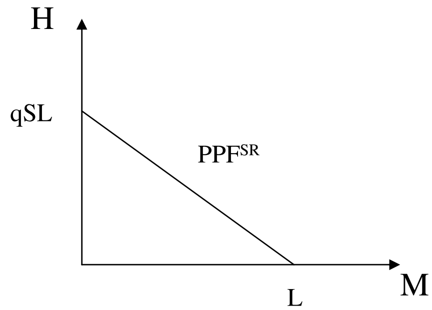

Figure 4.1: Autarky

Demands are then determined by their respective income shares, as usual:[171] $H = \frac{\beta w}{p}, M = \frac{(1-\beta)w}{1}$ and on aggregate

$$H = \frac{\beta L}{p}, M = (1-\beta)L, \text{ for } w = 1, \tag{4.5}$$

where L is the total endowment of labour, which coincides here with total population.

4.2.3 The Short Run Autarkic Equilibrium

Since there is only one primary factor L, the economy is Ricardian and the temporary production possibilities frontier will be a straight line, as both firms' and consumers' problems assume a fixed stock of the resource S. Notice the fact that in the short run the negative production externality does not manifest itself.[172] For a given stock of the resource S, $L_H = \frac{H}{qS}$, while $L_M = M$. The labour employment in the economy is divided between harvesting and manufacturing: $L = M + \frac{H}{qS}$ which implies that

$$H = qSL - qSM$$

[171] Yet another assumption implicit in our model is that pollution or perceived water quality does not shift demand for fish, as in McConnel and Strand (1989), p. 285-287), where consumers use water quality as an indicator of fish quality. There, better water quality under open access may have the perverse effect of reducing social surplus.
[172] Therefore, the problem is so far similar to Brander and Taylor (1997).

describes the linear temporary PPF represented in Figure 4.1. The short-run equilibrium is found by equating expressions (4.4) and (4.5). This yields

$$H = q\beta LS \text{ and } M = (1-\beta)L \tag{4.6}$$

as the short-run equilibrium outputs.

In autarky, the use of labour in manufacturing (and therefore the amount of pollution) is pre-determined, due to fixed proportionality. Then, the evolution of the stock of resource in the short-run can be obtained by subtracting the effect Z of manufacturing on the change of stock S from the growth expression, and then interacting it with the harvest function to find the open-access level of stock S^O.

In Figure 4.2, A would be the open-access extraction point in the absence of the manufacturing sector, or if there was no production externality: $\alpha = 0$.[173] With pollution, we have:

$$Z(t) = \alpha(1-\beta)L$$

which would be a straight line if represented in the space of Figure 3.2. Given the level of pollution Z, which is not a function of the stock S, the open-access stock equilibrium condition for the renewable resource is still that: $\frac{dS}{dt} = 0$, which implies

$$H(t) + Z(t) = G(S(t)). \tag{4.7}$$

As it is apparent from the picture, the harvest will take place at a lower level in the presence of pollution of the stock, as one would expect.

Substituting the known expressions into (4.7) we get:

$$q\beta LS + \alpha(1-\beta)L = rS(1-\frac{S}{K})$$

which is a quadratic equation yielding two possible steady states S_1^A and S_2^A as functions of the parameters.

Solving the quadratic equation:

$$\frac{r}{K}S^2 + (q\beta L - r)S + \alpha(1-\beta)L = 0$$

yields as discriminant $\Delta = (q\beta L - r)^2 - \frac{4r}{K}\alpha(1-\beta)L$ and the roots are:

$$S_{1,2} = \frac{r - q\beta L \pm \sqrt{\Delta}}{2r/K}.$$

[173] TC and TR stand for total costs and total revenues, respectively.

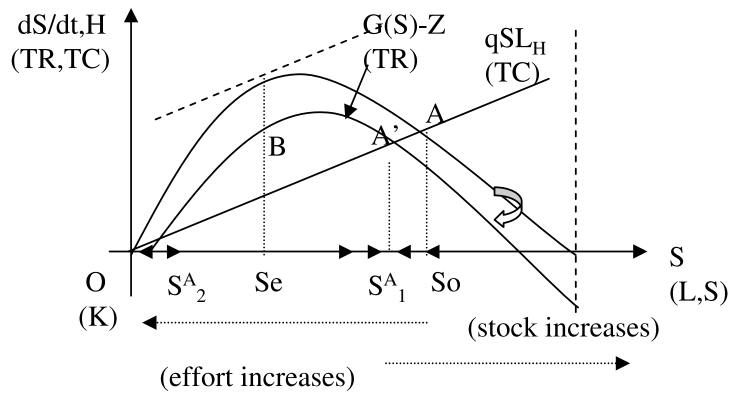

Figure 4.2: Effects of pollution on stock growth and open-access harvesting

When $\Delta > 0$, the roots are real and there exists a non-extinction steady-state (SS). If $\Delta < 0$, then, due to pollution and the given cost of harvesting, there is no interior solution: no feasible fishery due to excessive pollution. The condition for the existence of real roots is that

$$(q\beta L - r)^2 > \frac{4r}{K}\alpha(1-\beta)L \tag{4.8}$$

which can be loosely translated as: high q (the productivity parameter in harvesting), high β (strong consumer preference for H), low intrinsic growth rate (r), high carrying capacity of the environment (K).

Denoting by S_1^A, S_2^A the two autarkic steady-state stock levels, notice from the graph in Figure 4.2 that S_1^A is stable, while S_2^A is not, where S_1^A is the lower root that equals $S_1 = \frac{r-q\beta L-\sqrt{\Delta}}{2r/K}$. This stability of the lower root can be easily seen graphically: for harvesting rates exceeding the natural growth function evaluated at S_1^A, the net growth of the resource stock is negative, while for harvesting rates below that value, the net growth is positive. Then, regardless of the starting stock level S_0, provided of course that it is not to the left of S_2^A,[174] the stock level will move to S_1^A in the long run closed economy.

Lemma: *The uninternalized effect of pollution brings the autarkic economy closer to the first best optimum.*

[174] The case of initial over-depletion of the renewable resource

This is obvious on the graph above, where S^A is closer to the efficient stock level S_e than the open-access, no-pollution level S_o. Intuitively this can be understood due to the fact that the two externalities have offsetting effects: pollution reduces the profitability of harvesting, thereby reducing the scope for overharvesting. The level of the stock in the long run under open access and with no pollution ($\alpha = 0$) is $S^A = K(1 - \frac{q\beta L}{r})$. Now plugging S_1^A into (4.4) and (4.6) we obtain as equilibrium solution $p^A = \frac{1}{qS_1^A}$ and $H^A = q\beta LS_1^A$, $M^A = (1-\beta)L$, respectively.

Note by referring again to the graph, that provided the level of pollution Z is too high, which is the same as saying if α, $(1-\beta)$, L are "too high,"[175] we can get the case where no exploitation of the resource is possible, due to the strong externality that decreases the stock and raises the costs of extraction. Also, if supposedly the growth function of the stock would be depensatory (which may be the case for some species or circumstances) instead of taking the compensatory logistic form, then it may be relatively easy to get extinction and total collapse of the extraction sector, in which case M ceases to create an externality in production. However, we will abstract from such corner solutions here and look instead at interior solutions, where the economy is diversified and the conditions necessary for $S_1^A > 0$ are met by the parameters.

4.2.4 Dynamics in Autarky and Non-Convexity

We turn at this point to analyze the dynamic transition towards the steady state in this economy. Recall that the PPF in the short run, i.e. for a given stock level S, is a straight line. In the long run, production adjusts and will be influenced by the cross-sectoral production externalities, potentially yielding a convex PPF. Because in a dynamic setting, the manufacturing sector imposes costs to harvesting, the points on the static PPF will likely not be maintained, with the important exception of the intercepts. Depending on the parameters, the PPF can now be bowed-in and the problem can become non-convex due to production externalities, as shown in the seminal paper by Baumol and Bradford (1972). The basic argument is that producing the two goods jointly renders some convex combinations infeasible due to the negative external effect. Consequently, points on the linear short-run PPF become infeasible in the long-run. In their 1999 paper, Copeland and

[175] which means, keeping the order, that: M is very pollution intensive, consumers have strong tastes for the manufacturing good or the country is very populous, respectively. Interpreting these conditions confirms the intuition for cases where no equilibrium with strictly positive stock of resources is possible.

Taylor show that such non-convexities can create surprising specialization and trade effects.[176] As will be argued below, in our particular case, due to a combination of internal (intra-industry) and external (inter-industry) negative stock effects, the shape of the PPF turns out to be more complex.

However, before these specific results are derived, a discussion of the Baumol and Bradford (1972) result that production externalities are sufficient to cause non-convex production sets deserves a brief digression that will hopefully help build some intuition. Here we simply summarize the argument in diagrammatic form. Assume the M industry is polluting the environment, imposing a negative spillover effect on the A industry that is sensitive to the quality of certain elements of the environment.[177] If there is a preferred (low cost) location for both outputs, then the production possibility frontier PPF is convex (the production set is non-convex) and spatial separation can in fact act as a 'palliative' to the problem, by expanding the feasible production set.

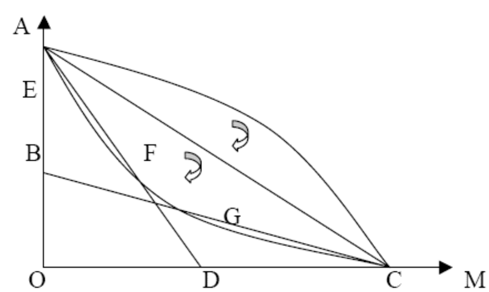

Figure 4.3: Non-convexity in the production set

Starting with a concave PPF (no spillover)[178] and increasing the level of the negative externality between sectors, the production frontier will bend towards the origin, and eventually become convex. Key to the reasoning is the fact that the end points of the PPF, namely E and C will not move when the externality becomes more significant, as they represent cases of total specialization in production, and thus, cases where cross-sectoral spillovers are

[176] See Copeland and Taylor (1999), p. 139

[177] M represents energy and A laundry producers in their example. Note the fact that the use of air pollution is avoided, as this would be unambiguously affecting consumers' utility and complicate the analysis.

[178] suppose the polluting industry is just starting the dirty manufacturing

immaterial. The convex production possibilities frontier EFGC corresponds to joint production of both inputs in the same location. If A is moved to the higher cost location, BC will be the relevant PPF, while in the case when M is moved there, AD will be the PPF.[179]

Thus, the production possibility set is non-convex provided the externality is strong enough. Moreover, spatial separation allows for higher total output, illustrated by the fact that the line segments AF and CG are situated above the respective arc/curve regions.

Returning to our model, we now move on to establish the curvature of the PPF in the long run autarky. But first let us state a somewhat surprising observation and defer the analysis of its implications in an effort to keep the model as simple as possible.

Lemma. *In a centralized framework, it is possible that the long-run social planner optimum involves partial unemployment of the labour force.*

An algebraic derivation is suggested in Appendix D. Intuitively, the long-run stock of the resource is decreasing in the total labour applied to harvesting and manufacturing. It may then be optimal, given certain parametric conditions, that total utility maximization involves leaving a fraction L_U of total population unemployed. This is easier to accept when a social planner solves the optimization problem. Here, however, we excluded any conscious planning or optimal management of the resources (S, L) whatsoever. Atomistic consumers do not realize that by increasing their effort the stock level is reduced and so will supply the full amount of labour in a Nash equilibrium. The introduction of another entirely 'clean' sector would allow getting around the unemployment issue. However, keeping this first model manageable dictates the exclusion of these interesting possibilities in the present paper, which assumes full employment in the steady state.

Recall the short run PPF[180] was $L = M + \frac{H}{qS}$. Also, from equation (4.1) one can write the change in the stock of the renewable natural resource as:

$$\frac{dS}{dt} = rS(1 - \frac{S}{K}) - qS(L - M) - \alpha M.$$

Hence, the steady-state level of stock has to satisfy:

$$rS(1 - \frac{S}{K}) - qS(L - M) - \alpha M = 0. \tag{4.9}$$

And the labour constraint can be written as:

$$L = M + \frac{H}{qS} \tag{4.10}$$

[179] Note that AD and BC do not have to be linear and can, in fact, be concave.
[180] see section 2.3 above.

To find the long-run PPF, we need to solve (4.9) for S and plug it into the expression (4.10) above. Solving the quadratic equation and deriving the production possibilities frontier involves some uninformative algebra, and is relegated to Appendix A. The autarkic stock S can be written as:

$$S^A = \frac{1}{2r}\{\sqrt{[q(L-M)-r]^2K^2 - 4r\alpha KM} - [q(L-M)-r]K\} \quad (4.11)$$

Plug this into (4.10) to obtain the steady-state PPF of the domestic economy:

$$H = \frac{q(L-M)}{2r}[\sqrt{K^2q^2(L-M)^2 + r^2K^2 - 2qK^2(L-M) - 4\alpha rKM} - \\ -Kq(L-M) + rK]. \quad (4.12)$$

As Appendix A details, convexity of the production possibility set reduces to the condition that a cubic in M be higher than zero, or the PPF^{LR} is convex for:

$$4K^2q^4(L-M)^3 - 3Kq^2(3Kq-2\alpha r)(L-M)^2 - 12\alpha Kq^2rM(L-M) + \\ +(3K^2q^2r^2 + 3K^2q^2 + 4\alpha^2r^2 - 8\alpha Kqr)(L-M) + 4\alpha r(Kq-2\alpha r)M - \\ -Kr^2(Kq-2\alpha r) > 0,$$

where α, K, q, r are parameters, L is the given population. As is apparent from this, the steady-state PPF is concave for some levels of M, given the parameters, and convex for others.

Proposition 1. *The long-run production possibilities frontier in M-H commodity space is convex-concave.*

Some further analysis implies that the cubic in M is positive for all values of M below a certain threshold M^* and negative for the others. In other words, the PPF^{LR} is concave $(\forall)$ $M > M^*$ and is convex $(\forall)$ $M < M^*$ for a certain limit level of M^*, a function of the parameters of the system. Then, given the single inflexion point M^*, the autarkic steady-state PPF will look like in Figure 3.4.[181] Notice that the PPF is convex in a neighbourhood of the H-axis, for values of M lower than the threshold M^* and concave in a neighbourhood of the M-axis, for values of M greater than M^*. The result concurs with the findings in Herberg and Kemp (1969)[182] and Panagariya

[181] Allowing for the possibility that some workers are idle in equilibrium does not change this qualitative result.

[182] See p. 414. Note that for the shape of the PPF around $H = 0$ in Fig.4 it suffices that we have DRS in H.

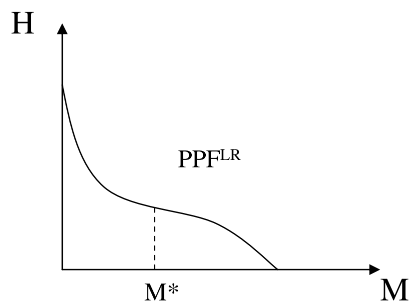

Figure 4.4: Convex-concave PPF

(1981),[183] which discuss the shape of the production possibilities curve when two sectors have different returns to scale.

In our case, the shape of the PPF could be explained intuitively as follows. When stock level is relatively high, the more damaging activity is harvesting. However, when stock decreases and harvesting becomes less efficient due to the implicit stock externality, manufacturing may become the more harmful activity.[184] For levels of M production lower than M*, starting from the case where all the labour force is involved in harvesting and stock is relatively low, an extra worker shifted from H to M will have a decreasing opportunity cost, due to the fact that the shift to M impacts negatively on the productivity of labour in H. Therefore, besides the direct level effect of reducing the labour applied to H, moving an extra worker to M production has a detrimental (negative but increasing) effect on the productivity of the remaining workers in H. However, beyond the threshold level M*, manufacturing starts having a lower negative impact on productivity in H than harvesting itself.[185] In other words, when there is a lot of manufacturing, resource stock is relatively high and harvesting is the more damaging activ-

[183] The result is also discussed in Ethier (1982), p. 1263.

[184] The condition for M to be less harmful than H in autarky is $S > \frac{\alpha(1-\beta)}{q\beta}$ and is more likely to hold the higher the stock level. This condition makes intuitive sense if we recall that it is harder to catch the resource when it is sparse, whereas the marginal damage from pollution is stock-independent. To make things interesting, we assume this condition can hold given our parameters.

[185] As derived in Appendix B, stock is not a monotonic function of M. In particular, $\frac{\partial S^A}{\partial M} < 0$ for $M < \underline{M}$ and $\frac{\partial S^A}{\partial M} > 0$ for $M > \underline{M}$.

ity for the resource. Then we are in the concave part of the PPF, where shifting an extra worker from H to M has an increasing opportunity cost due to the additional productivity benefit in H.

Proposition 2. *The autarkic equilibrium is not efficient. It depends on the relative demand for the two commodities and on the relative strength of the externalities as sources of inefficiency.*

The shape of the production possibilities frontier is important in deciding the pattern of specialization triggered by trade. Still looking at the closed economy, the autarkic equilibrium outputs determined above are: $H^A = q\beta LS^A$ which implies $\beta L = \frac{H^A}{qS^A} = H^A p$ and $L = \frac{M^A}{1-\beta}$, where p is the autarkic relative price. Then we have $\frac{\beta}{1-\beta}M^A = H^A p$ and $\frac{dH}{dM} = \frac{1}{p} \cdot \frac{\beta}{1-\beta} - \frac{M^A}{p^2} \cdot \frac{\beta}{1-\beta}\frac{dp}{dM}$, where $\frac{1}{p}$ is in fact the relative price line in a figure like 3.4 above. Then we can compare the slope of the PPF at the equilibrium with the slope of the relative price. The condition that the slope of the PPF is higher than the slope of the price line reduces to:

$$\frac{2\beta - 1}{1-\beta} > \frac{L}{p}\frac{dp}{dM}.$$

Notice that for $\beta > \frac{1}{2}$, i.e. when domestic taste for H is strong and the equilibrium occurs in the convex part of the PPF, the price line can be flatter than the PPF slope. Alternatively, if $\beta < \frac{1}{2}$, i.e. when domestic taste for M is strong the price line tends to be steeper than the PPF at the autarkic equilibrium.

In the first case, with more general preferences, two equilibria can emerge, one in the convex, one in the concave part of the PPF, while in the second case the internal equilibrium is unique. It is argued in Appendix C that in a static setting, opening up to trade from such an autarkic equilibrium can bring about any pattern of specialization/diversification, as international trade acts as a vent for the internal inter-sectoral tensions existing in the autarkic economy. We will return to use the results in the next section of the paper.

Therefore, the autarkic equilibrium is likely to be situated at a point where the price line is not tangent to the PPF, due to the external effects. If the domestic price line is steeper than the PPF at equilibrium, the market undervalues the true cost of the harvesting good H. Expanding production of M generates a negative externality on H, the 'private' exceeds the 'social' marginal productivity of labour in M and so there is overemployment of labour in M compared to what is efficient. If, on the contrary, the domestic price line is flatter than the slope of the PPF at equilibrium, the market undervalues the true cost of M due to the open-access externality. The following discussion of the effects of trade will assume the first scenario: there is a relatively strong domestic demand for M, the autarkic price line steeper than the slope of the production frontier and a unique autarkic equilibrium.[186]

Proposition 3. *The supply of manufacturing is not monotonic over the feasible price: there exists a critical point where the slope of supply of M changes sign.*

In order to study the stability properties of the autarkic equilibrium, plug the expression for the stock derived in (4.11) into the relation between the relative price and the stock found in (4.4) to get the inverse supply function:

$$p = \frac{1}{qS^A} = \frac{2r/q}{\sqrt{[q(L-M)-r]^2K^2 - 4r\alpha KM} - [q(L-M)-r]K} \tag{4.13}$$

The sign of the first derivative of S^A with respect to M is not unambiguous.[187] We get the sufficient condition that the supply of M is upward sloping for:

$$M > L - \frac{r}{q} + \frac{2r\alpha}{q^2K} \tag{4.14}$$

While this is not a necessary condition[188] and so it does not allow by exclusion the identification of a complementary inequality that makes the supply upward sloping, it shows that supply can be downward sloping over a range.

The intuition behind Figure 4.5 is the following. Initially, higher M yields lower stock level S and lower productivity in H, which causes labour to shift from H to M and lowers the price necessary for firms in M to break even, as $\frac{1}{p} = qS$. This is a result commonly obtained in the increasing returns to scale trade models.[189] Increasing production of manufacturing goods beyond $\underline{M}$ requires a higher price due to the fact that production moves along the PPF in the concave section, where the opportunity cost of producing more manufactures is increasing. Notice from equation (4.12) that the relationship between M-production and the relative price is not monotonic, and so the price increases after supply of M reaches a threshold value.

[186] See Eaton and Panagariya (1979), p. 590, for a similar discussion.
[187] See appendix B for derivation.
[188] Such a condition has a much more complicated expression. See Appendix B for details.
[189] E.g. Ethier (1982).

As Copeland and Taylor (1999) note,[190] generally, multiplicity of equilibria is - even in closed economies - a feature of the increasing returns to scale models. Here, due to our utility assumption, demand for M is $M^D = (1-\beta)L$ a vertical line in the (M, p) space like in Figure 3.5, and the autarkic equilibrium is at E or E'. In autarky the economy will stay diversified due to the fact that both goods are essential for consumers. When opening up to trade, the small open economy takes world price p^w as given and three possible equilibria emerge. The IRS literature result is that a diversified equilibrium with trade becomes problematic (it is unstable) and specialization becomes possible. However, as we argued before, all this is valid here only for a range of M values (lower than $\underline{M}$). For the other possible levels of manufacturing good production we *can* have a diversified equilibrium even under free trade.[191]

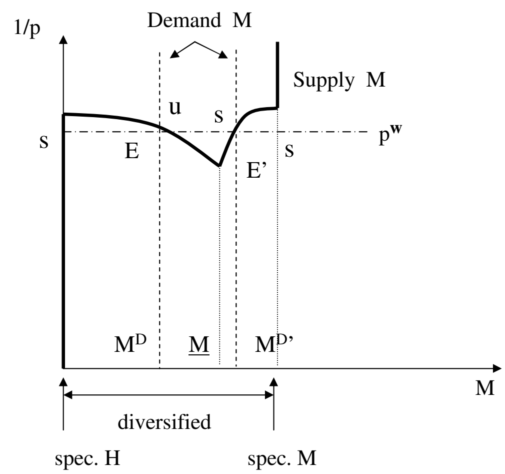

Figure 4.5: Equilibria

Thus, as can be seen in Figure 4.5, there are stable trading equilibria both when the economy is specialized and when diversified. Trade oppor-

[190] See argument on p. 145, Copeland and Taylor (1999).

[191] Note that by altering the structure of the problem we may eliminate some of the cases and make the results clearer. Yet, one of the purposes of the paper is to show that under the conditions specified in the model, any specialization / diversification outcome is possible once the economy opens up to trade. This is a source of the different results from the literature.

tunities create an infinitely elastic demand for the goods produced domestically. If domestic demand for M under autarky is at $M^D < \underline{M}$, trading (at domestic prices) will make the autarkic equilibrium unstable. A small perturbation that increases production of the manufacturing good will be self-reinforcing and push for further specialization in M. If domestic demand is at $M^{D'} > \underline{M}$, the autarkic equilibrium will still be stable and so no specialization is induced if trade begins at autarkic prices. The analysis is simpler when considering trade at international prices that differ from the pre-trade domestic price. For world prices $(1/p^w)$ low enough the economy will completely specialize in H, while for prices high enough, the economy will specialize in M, as is apparent from the graph.

4.3 The Open Economy Equilibrium

In the Brander and Taylor (1997) model, a country that exports the manufacturing good must gain from trade, and a country that has a comparative advantage in the resource good but fails to fully specialize in it necessarily losses from trade. In the present model this need not happen, as increased pollution caused by specialization in the dirty good hurts the resource.[192] Partially specializing in M increases the pollution pressure on the stock of the resource if M is more damaging than H. Full specialization in H may make the small open economy better off. From here one can learn that a successful industrialization process in a resource-abundant developing-country must take pollution into account.

The analysis of the welfare changes brought about by trade in our small economy looks first at the short-run impact and then the long-run effects are derived. In the short-run, the PPF is linear. When opening up to trade, the small economy takes as given the international price p^w. If we denote by p the autarky steady-state price, there are three possible cases: $p < p^w$,

[192] A similar conclusion is reached by Hannesson (2000). He takes the Brander and Taylor model (which assumes constant returns to scale in the production of the other goods) and introduces decreasing returns in the other (non-resource) sector. The outcome is the inverse of the Brander and Taylor result: the country that partially specializes in the resource sector can gain from trade, as the losses of increasing production in the diminishing returns alternative sector can be limited through imports. Our setup differs from his in that it explicitly considers the production externality and the returns are constant in the manufacturing sector and could be decreasing in the resource sector. So, while he obtains a hump-shaped steady-state PPF, ours looks like in Figure 4.4.

$p > p^w$ or $p = p^w$. If $p > p^w$, the country has a comparative advantage in M, will start by specializing in M (if the world demand for M is strong enough, which we assume here for the small economy case). Then $M = L$ and the stock will evolve to S^M. Depending on the parameters, we may get extinction of the stock if S^M becomes zero.

If $p < p^w$, the country has a comparative advantage in H, will specialize in H (again, given world demand for H is "large"). There will be more harvesting in the economy, so the overexploitation problem worsens, but there is no pollution-related negative impact on the stock. In a third case, if $p = p^w$, the international price is exactly equal to the autarkic opportunity cost of producing H, and so there are no areas of comparative advantage. However, if the autarky-inherited equilibrium is perturbed by increasing the M production, then productivity in the H-sector declines if the stock decreases - i.e. $S^T < S^A$- as a result of the perturbation.[193] If the autarkic equilibrium were at a point like E in Figure 4.5, this is a self-reinforcing process, leading to further specialization in M, and so the initial autarkic diversified equilibrium is unstable. If at E' in autarky, the pre-trade equilibrium is stable and there will be no welfare changes taking place. If, on the contrary, $S^T > S^A$, meaning that the M sector is relatively *less* harmful to the natural resource than harvesting, then productivity in H improves and the economy will return to a diversified production state.

The effect of trade on welfare can be seen in a simple setting that depicts the short-run responses of the PPF and PPC.

4.3.1 Comparative Advantage in the Resource Good

For Case 1, $p < p^w$ leads to comparative advantage in the resource good and specialization in H in the small open economy. If H specialization is more harmful than diversified autarkic production, then the stock of resource decreases and so does the feasible level of H. Then the PPF rotates downward as in Figure 4.6, bringing the PPC down with it. In the short run (SR) there are welfare gains, as the feasible budget set is now the upper price line in Figure 4.6, while the PPF is still the autarkic one. However, overexploitation of the resource dominates the beneficial pollution reduction as far as the stock is concerned and so the autarkic equilibrium becomes unfeasible. In the long run (LR) the stock S is lower and welfare (W) is lower because the feasible consumption set shrinks, and we eventually get diversification

[193] Like in Copeland and Taylor (1999), p. 147.

in production in the long run.[194]

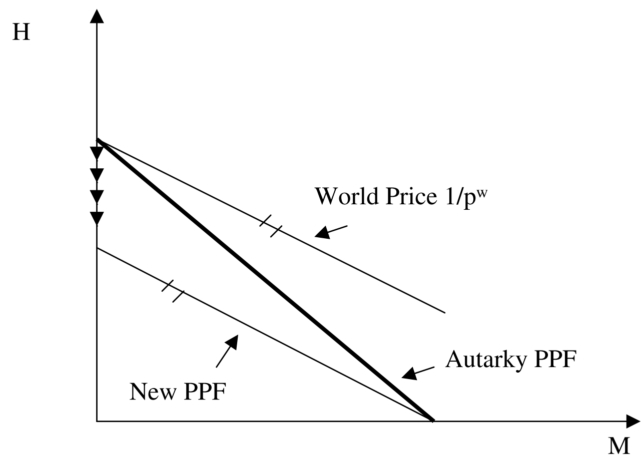

Figure 4.6: Overdepletion due to trade decreases H productivity

If, on the contrary, $S^A < S^H$ and the specialization in H allows the stock to actually rebound, the PPF rotates upward and the country experiences short-run gains from trade, as can be seen in Figure 4.7. Here, unlike in Brander and Taylor (1997), initial specialization in H may make the country better off. This result is obtained due to the beneficial result of spatial separation of industries. If the manufacturing is relatively more damaging to the resource, trade allows for an avenue to decrease the tensions created by the pollution externality. Like in Copeland and Taylor (1999), this non-traditional source of gains from trade can - for some values of the parameters - offset the fact that the other source of inefficiency, namely the open access problem, inevitably worsens.

4.3.2 No Areas of Comparative Advantage for the Small Open Economy

For the relatively more complicated Case 2, $p = p^w$ does not confer any clear comparative advantage to the country opening up to trade. If we assume a perturbation by slightly increasing M-production, then H-production decreases as a result of the externality. If M is relatively more damaging,

[194] This is confirmed in Appendix C, where Figure C1 depicts the movement from the autarkic to trade production along the long-run PPF.

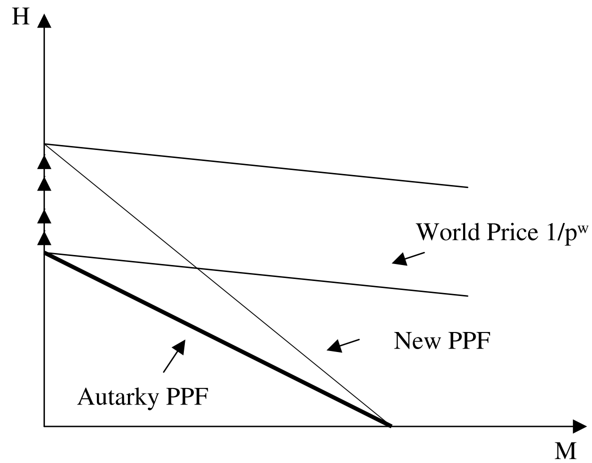

Figure 4.7: Harvesting is relatively less damaging

then S falls, production of H falls more in the longer run, like in Figure 4.8.[195] In the extreme case of complete specialization in M, the economy does not experience a welfare loss from trade in the long-run, as the pre-trade bundle is still feasible because the PPC stays unchanged at the world price line.[196]

If M is relatively less damaging, S rises, H-production rises and the PPF rotates up like in Figure 4.7. Therefore, the stock increases and also welfare increases. However, as labour productivity is higher in H, there will be a shift of workers from M to H and the PPF can rotate back to be again coincidental with the international price line and a diversified equilibrium obtains again in the long run. The overall welfare effect is positive.

If, however, the perturbation of the diversified equilibrium is done by positively shocking H-production, then if H is relatively more damaging we can get the situation in Figure 4.6 above. Starting at E in Figure 4.5, the diversified equilibrium is unstable and it yields lower S and lower W. Yet, starting at E', there will be no welfare effect in the long run for the diversified economy, as the production point will return to the pre-trade position. If H is relatively less damaging, then we get a situation similar to the one illustrated in Figure 4.7 above, the diversified equilibrium is unstable and we can get higher S and W. Note here how trade arises as a means to

[195] Here we can potentially get extinction of the stock due to the self-reinforcing pattern of comparative advantage in M.
[196] This result parallels one obtained in Brander and Taylor (1997).

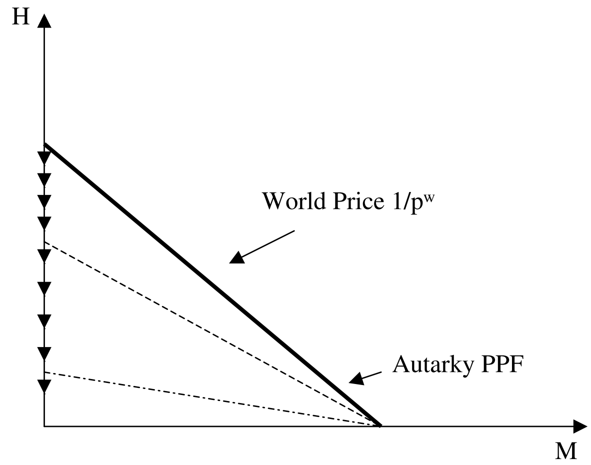

Figure 4.8: Harvesting is relatively more damaging

spatially separate the two industries even in the absence of a price-dictated comparative advantage.[197]

Thus, to summarize the discussion of these two cases, we can state the following result:

Proposition 4. *Specialization in the resource sector can be welfare improving in the long run, provided that harvesting is relatively less damaging to the growth of the resource.*

4.3.3 Comparative Advantage in the Manufactured Good

In a third case, $p > p^w$ the country has a comparative advantage in the manufacturing good production and can increase manufacturing good production when opening up to trade. Again, given the relative harm inflicted by the two sectors on the stock of renewable resource, the economy may lose from trade. In Figure 4.9, if harvesting is relatively more damaging for the stock, specializing in M reduces the pressure on the resource and allows the PPF to rotate upwards, increasing the productivity in harvesting. When the PPF becomes coincidental with the world price line $1/p^w$, a diversified equilibrium is possible where the economy can experience a long run welfare gain, even though the PPF can actually rotate back, depending on the production mix. However, if the manufacturing sector is relatively more

[197] This is one of the defining features of the Copeland and Taylor (1999) model.

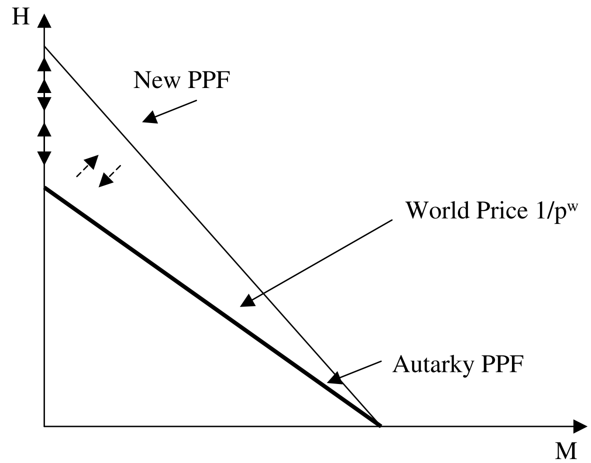

Figure 4.9: Comparative advantage in M

damaging, the economy will behave similarly to what we already described in Figure 4.6 above. Here the economy experiences net loses in welfare terms in all cases except the long-run full specialization in M case. Thus:

Proposition 5. *Specialization in the manufacturing sector can be welfare reducing in the long run, provided that manufacturing is relatively more damaging to the growth of the resource.*

Intuitively, the tradeoffs at play here are the following: If $p^A < p^w$, then H can expand and M can contract and so adding to the usual gains from trade, the overdepletion problem worsens, while the pollution problem improves. If $p^A > p^w$, M can expand and H can contract and the economy experiences less overdepletion, but more pollution to add to the gains from trade. Note that while even partial spatial separation of the two sectors allowed by trade adds to welfare, the persisting externality acts in the opposite direction. This leads to net results that are less categorical than those in the baseline models. To summarize the results above, taking our preferred case whereby manufacturing sector is inflicting relatively more damage on the stock (per unit of effort) than the harvesting per se,[198] we can say that opening up to trade seems to benefit the small open economy if it specializes in the traditional/environment-based sector. A resource exporter benefits from trade, taking advantage of the separation of the two industries, while a resource importer can in fact do worse than in autarky,

[198] This could be rationalized by the fact that harvesting affects only a fraction of the stock, while pollution has a broader and longer-lasting impact on the resource.

as pollution problem worsens. This result is largely due to the fact that here the production externality dominates the overaccess problem. The results are changing dramatically if the relative harmfulness of the two sectors is inversed: If harvesting is more damaging for the resource, exporting H is welfare reducing, while specializing in M is welfare improving in this case. Here the overaccess externality dominates pollution in its negative effects and the economy does better by industrializing.

4.4 Conclusion

To conclude, our model is different in its predictions from the two models that were used as benchmarks. In Copeland and Taylor (1999), free trade was welfare improving for the small economy. In Brander and Taylor (1997) free trade was dominated by autarky from a welfare perspective for a diversified resource exporter. In our model with renewable resource and negative production externality, if the small open economy specializes in the sector that is less damaging for the stock of resource, trade can be welfare improving. Trade exacerbates the open-access over-harvesting. Yet, by the industry separation permitted by openness, the negative production externality declines in importance as a source of inefficiency. Moreover, complete specialization in the resource good is not needed in order to gain from trade. If the harvesting sector is relatively harmless for the resource stock, there will be gains. Unlike the Copeland and Taylor (1999) model, free trade may be welfare reducing, even when there is initial specialization in production, if specialization takes place in the relatively more environmentally-harmful sector.

The central message of the paper is that pollution can have non-negligible welfare effects *even* when there are no significant negative repercussions for consumers (possibly due to a relatively clean overall environment in a developing economy). Environmental Kuznets Curve (EKC) literature-inspired advice that income-augmenting development eventually brings cleaner environment may be misguided in the presence of negative production spillovers. It is argued that the country may lose in welfare terms even when exporting the industrial good. This occurs because of the negative resource stock effect of the dirty good manufacturing and the repercussions on the "traditional" or environment-intensive sector. Under this scenario, even though overexploitation of the open-access resource is not a problem exacerbated by trade openness, pollution depletes the resource and brings down productivity in the resource-intensive sector. To the extent that the negative effect dominates, the country as a whole loses from trade. On the other hand, if the small open economy specializes in the resource good, even incompletely, it may stand to gain from trade. In short, a possible policy lesson for a developing renewable resource-rich economy is that industrializing at the expense of traditional sectors may in fact lead to welfare losses, while specialization in the resource-based sectors may lead to gains.

The paper looks at open access resources in a small open economy. Possible extensions, that include endogenizing the international trading price formation in a two-country setting, allowing for environmental policy in the form of taxes, or establishment of property rights, together with are candidate subjects for future study.

APPENDIX A:

This appendix derives the steady-state production possibilities frontier for the autarkic economy and provides the conditions for the local concavity and convexity of this PPF.

From the steady-state condition for the stock S we obtain the expression in equation (4.9) in the text:

$$rS(1-\frac{S}{K})-qS(L-M)-\alpha M=0. \tag{4.15}$$

which, together with the short-run PPF (or the labour constraint)

$$L=M+\frac{H}{qS} \tag{4.16}$$

give the desired result.

Solving the quadratic equation in (1) yields as positive solution:[199]

$$S^A=\frac{\sqrt{[q(L-M)-r]^2K^2-4r\alpha KM}-[q(L-M)-r]K}{2r}.$$

Plugging this into (2) we get the desired PPF as:

$$H=\frac{q(L-M)}{2r}[\sqrt{K^2q^2(L-M)^2+r^2K^2-2qK^2(L-M)-4\alpha rKM}- \\ -Kq(L-M)+rK]. \tag{4.17}$$

Take first and second order derivatives to analyze the convexity properties of this long-run PPF:

$$2r\cdot\frac{\partial H}{\partial M}=-q[\sqrt{K^2q^2(L-M)^2+r^2K^2-2qK^2(L-M)-4\alpha rKM}- \\ -Kq(L-M)+rK]+ \\ +q(L-M)[\frac{qK^2-K^2q^2(L-M)-2\alpha rK}{\sqrt{K^2q^2(L-M)^2+r^2K^2-2qK^2(L-M)-4\alpha rKM}}+Kq]. \tag{4.18}$$

$$2r\cdot\frac{\partial^2 H}{\partial M^2}=qK[\frac{Kq^2(L-M)-qK+2\alpha r}{\sqrt{K^2q^2(L-M)^2+r^2K^2-2qK^2(L-M)-4\alpha rKM}}+q]- \\ -q[\frac{qK^2-K^2q^2(L-M)-2\alpha rK}{\sqrt{K^2q^2(L-M)^2+r^2K^2-2qK^2(L-M)-4\alpha rKM}}+Kq]- \tag{4.19}$$

[199] under the usual parametric conditions for the existence of roots in R.

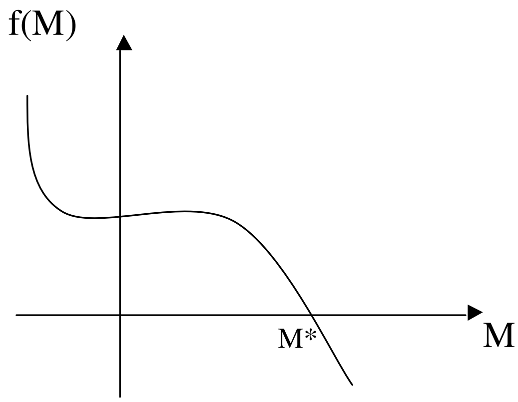

Fig. A

$$-q(L-M)K\cdot\frac{-Kq^2\sqrt{K^2q^2(L-M)^2+r^2K^2-2qK^2(L-M)-4\alpha rKM}}{K^2q^2(L-M)^2+r^2K^2-2qK^2(L-M)-4\alpha rKM}-$$

$$-[Kq^2(L-M)-qK+2\alpha r]\cdot\frac{(\sqrt{K^2q^2(L-M)^2+r^2K^2-2qK^2(L-M)-4\alpha rKM})'}{K^2q^2(L-M)^2+r^2K^2-2qK^2(L-M)-4\alpha rKM}.$$

To obtain the conditions under which this expression is positive, drop some positive factors that do not influence the sign and get:

$$\frac{\partial^2 H}{\partial M^2}>0\Leftrightarrow[3Kq^2(L-M)-qK+2\alpha r]\cdot[q^2K(L-M)^2+r^2K-2qK(L-M)-$$

$$-4\alpha rM]+(L-M)[Kq^2(L-M)-qK+2\alpha r]^2>0. \qquad (4.20)$$

After further manipulation, this simplifies to the condition that a cubic in M be positive:

$$4K^2q^4(L-M)^3-3Kq^2(3Kq-2\alpha r)(L-M)^2-12\alpha Kq^2rM(L-M)+$$
$$+(3K^2q^2r^2+3K^2q^2+4\alpha^2r^2-8\alpha Kqr)(L-M)+4\alpha r(Kq-2\alpha r)M-$$
$$-Kr^2(Kq-2\alpha r)>0.$$

As it appears, we need to derive the conditions under which this cubic function of M with a negative M^3 coefficient is above the M-axis. The function looks somewhat like in the figure above.

Notice that the function is positive for M below a certain level M^*, and so this is also the condition for the long-run PPF of the autarkic economy to be convex. For $M>M^*$ the PPF is concave.

APPENDIX B:

This appendix derives the supply of M in autarky as a function of the relative price p and provides the conditions for obtaining a downward sloping section on the inverse supply function.

Plugging the expression for the stock derived in (4.11) into the relation between the relative price and the stock found in (4.4), we get the inverse supply function:

$$p = \frac{1}{qS^A} = \frac{2r/q}{\sqrt{[q(L-M)-r]^2K^2 - 4r\alpha KM} - [q(L-M)-r]K} \qquad (4.21)$$

where p is a function of the inverse of the stock level S^A. Note that the inverse supply function for M should have the form $\frac{1}{p}(M)$, and therefore the partial derivatives of p and S with respect to M have the same sign. Taking the derivative of S^A with respect to M gives the following expression:

$$\frac{2r}{K} \cdot \frac{\partial S^A}{\partial M} = \frac{2q[r - q(L-M)] - 4r\alpha/K}{\sqrt{[q(L-M)-r]^2 - 4r\alpha M/K}} + q. \qquad (4.22)$$

By quick inspection of equation (8) it can be noticed that a *sufficient* condition for the partial derivative to be positive, which is also the condition for the supply of M to be upward sloping, is that the numerator of the fraction be positive, which translates into:

$$q[r - q(L-M)] - 2r\alpha/K > 0$$

or

$$M > L - \frac{r}{q} + \frac{2r\alpha}{q^2K}. \qquad (4.23)$$

The less restrictive *necessary* condition for the supply of M to be upward sloping is:

$$2q[r - q(L-M)] - 4r\alpha/K + q\sqrt{[q(L-M)-r]^2 - 4r\alpha M/K} > 0$$

condition which is satisfied for all M above a critical level which is going to be less than the sufficient condition in (3) above.

Then the inverse supply of M is actually downward sloping for $M < \underline{M}$ and upward sloping for $M > \underline{M}$.

Hence, depending on the parameter values, there may be a range of feasible M values for which the supply is negatively sloped, leading to greater specialization in M and a self-reinforcing comparative advantage dynamics as obtained in the IRS trade literature. Yet for some values of M outside this range, supply of M is actually upward sloping and the tendency towards complete specialization found in Copeland and Taylor 1999 is countered.[200]

APPENDIX C:

This appendix shows how opening up to trade can influence the production and specialization patterns, starting from autarkic equilibrium points like A^1 (in the concave region) or A^2 (in the convex region) when there are *no inter-temporal* considerations, i.e. when the stock of resources is at its steady state level. For simplicity, suppose that the autarkic equilibrium is situated in the concave to the origin part of the long-run PPF.[201] Also, following the discussion of the efficiency of the autarkic equilibrium in the text, assume that, due to the externalities involved, the autarkic price line is steeper than the slope of the PPF at the equlibrium.

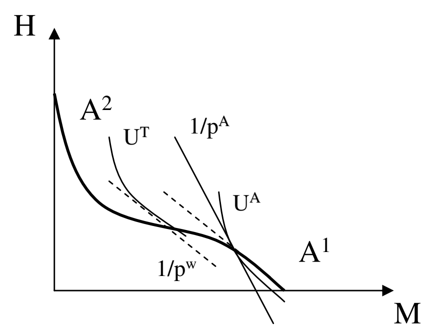

Fig. C1

Let $\frac{1}{p^w}$ be the international price that the small economy takes as given. Then if this is lower than the previous autarkic price, i.e. if $\frac{1}{p^w} < \frac{1}{p^A}$, the economy will move to produce more H as this is its area of comparative advantage. It can be seen from the first graph above that in this case the

[200] The critical value M_2 above which the supply of M is necessarily upward sloping is called $\underline{\text{M}}$ in the paper.
[201] Eaton and Panagariya argue that equilibria in the convex part are unstable, due to the perverse supply behavior with respect to price changes.

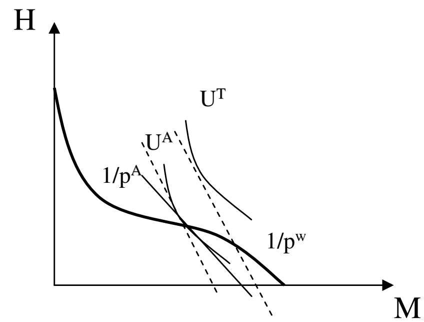

Fig. C2

autarkic equilibrium dominates the trading one from a welfare perspective, as U^T is below U^A. The explanation is that moving to the new equilibrium point along the PPF shifts labour from M to the less productive/lower returns to scale sector, H.[202] The economy experiences a long run welfare loss, as it moves labour to the externality-ridden sector H.

If, on the contrary, $\frac{1}{p^w} > \frac{1}{p^A}$, as in the second graph, then the economy tends to move towards producing more M, where it has a comparative advantage. Full specialization in M is possible. Also, following specialization in M the economy can experience a long run gain in welfare.

Notice that any pattern of specialization or diversification is possible. Unlike Brander and Taylor, specialization in H is possible. Unlike Copeland and Taylor, it may yield losses for the small open economy. Also, specialization in the manufacturing good can yield long run gains.

APPENDIX D:

This appendix explains how to determine whether in the steady state some labour will be left idle.

If the consumer takes the stock of the resource S as given, chooses the amount of labour to be allocated to H, M, leaves some fraction unemployed and solves:

$$\underset{L_H,L_M}{Max} \quad U = H^{\beta}M^{1-\beta} = (qSL_H)^{\beta} \cdot L_M^{(1-\beta)} \; s.t. \; L = L_H + L_M + L_U.$$

[202] See Choi and Yu, op. cit., p. 984.

The solution to this static optimization problem is: $L_H = \frac{\beta(L-L_U)}{\beta+(1-\beta)qS}$ and $L_M = \frac{(1-\beta)qS(L-L_U)}{\beta+(1-\beta)qS}$.

In a first best scenario, a planner realizes that the stock is a function of total labour utilized in production. In the specification above, the consumer practically internalizes the negative externality imposed by working in any sector on productivity in the H sector and may chose to work less ($L_U > 0$). The implicit coordination issues could be resolved when a social planner solves the optimization problem.

The possibility of leaving workers idle in autarky raises the interesting question of the impact of trade on this optimal labour allocation.

Bibliography

[1] Daron Acemoglu, Simon Johnson, and James A. Robinson. The colonial origins of comparative development: An empirical investigation. *The American Economic Review*, (5):1369-1401, dec.

[2] Daron Acemoglu and James A. Robinson. *Economic Origins of Dictatorship and Democracy.* Cambridge University Press: New York, 2005.

[3] Alberto Alesina, Arnaud Devleeschauwer, William Easterly, Sergio Kurlat, and Romain Wacziarg. Fractionalization. *Journal of Economic Growth*, 8:155-194, 2003.

[4] Michael V. Alexeev and Robert F. Conrad. The elusive curse of oil. *Review of Economics and Statistics forthcoming*, 2008.

[5] W. C. Allee, A. E. Emerson, O. Park, T. Park, and K. P. Schmidt. *Principles of Animal Ecology.* Saunders, Philadelphia, 1949.

[6] Silje Aslaksen and Ragnar Torvik. A theory of civil conflict and democracy in rentier states. Working paper series, Department of Economics, Norwegian University of Science and Technology, May 2005.

[7] Jean-Paul Azam. The redistributive state and conflicts in africa. *Journal of Peace Research*, 38(4):429, 2001.

[8] Jean-Paul Azam and Alice Mesnard. Civil war and the social contract. *Public Choice*, 115(34):455-75, 2003.

[9] Jean-Marie Baland and Patrick Francois. Rent-seeking and resource booms. *Journal of Development Economics*, 61(2):527-542, April 2000.

[10] Jean-Marie Baland and Jean-Philippe Platteau. *Halting degradation of natural resources : is there a role for rural communities?* New York : Food and Agriculture Organization of the United Nations ; Oxford, England : Clarendon Press, 1996.

[11] Karen Ballentine and Jake Sherman, editors. *The Political Economy of Armed Conflict: Beyond Greed and Grievance*. Lynne Rienner Publishers, London, 2003.

[12] Ian Bannon and Paul Collier, editors. *Natural Resources and Violent Conflict: Options and Actions*. The World Bank: Washington, D.C., 2003.

[13] Edward Barbier, Richard Damania, and Daniel Leonard. Corruption, trade and resource conversion. *Journal of Environmental Economics and Management*, 50(2):276-299, 2005.

[14] Edward B. Barbier and Michael Rauscher. Trade, tropical deforestation and policy interventions. *Environmental and Resource Economics*, 4(1):75-90, 1994.

[15] Edward B. Barbier and Carl-Erik Schulz. Wildlife, biodiversity and trade. *Environment and Development Economics*, 2(02):145-172, March 2001.

[16] Pranab Bardhan. *Scarcity, Conflicts, and Cooperation*. MIT Press, Cambridge, MA, 2005.

[17] William J Baumol and David F Bradford. Detrimental externalities and non-convexity of the production set. *Economica*, 39(154):160-76, May 1972.

[18] Dirk Bergemann and Juuso Valimaki. Dynamic common agency. Discussion papers, Northwestern University, Center for Mathematical Studies in Economics and Management Science, November 1999.

[19] Douglas Bernheim and Michael Whinston. Menu auctions, resource allocation, and economic influence. *The Quarterly Journal of Economics*, 101(1):1–31, February 1986.

[20] Trond Bjørndal and Gordon Munro. *The Management of High Seas Fisheries Resources and the implementation of the UN Fish Stock Agreement of 1995*, chapter in Folmer, Henk and Tom Tietenberg (eds.) The International Yearbook of Environmental and Resource Economics 2003/2004, Edward Elgar Publishing, 2003, pages 1-35.

[21] Christopher Blattman and Edward Miguel. Civil war. *Journal of Economic Literature (forthcoming)*, 2008.

[22] Valerie Bockstette, Areendam Chanda, and Louis Putterman. States and markets: The advantage of an early start. *Journal of Economic Growth*, 7(4):347–69, December 2002.

[23] Kenneth A. Bollen, David K. Guilkey, and Thomas A. Mroz. Binary outcomes and endogenous explanatory variables: Tests and solutions with an application to the demand for contraceptive use in tunisia. *Demography*, 32(1):111-131, Feb 1995.

[24] Katharine Bolt, Mampite Matete, and Michael Clemens. *Manual for Calculating Adjusted Net Savings*. Environment Department, World Bank, September 2002.

[25] Axel Borrmann, Matthias Busse, and Silke Neuhaus. Institutional quality and the gains from trade. *Kyklos*, 59(3):1-26, August 2006.

[26] James A. Brander and M. Scott Taylor. International trade between consumer and conservationist countries. *Resource and Energy Economics*, 19(4):267-297, November 1997.

[27] James A. Brander and M. Scott Taylor. Open access renewable resources: Trade and trade policy in a two-country model. *Journal of International Economics*, 44(2):181-209, April 1998.

[28] James A. Brander and M. Scott Taylor. International trade and open-access renewable resources: The small open economy case. *Canadian Journal of Economics*, 30(3):526-52, August 1997.

[29] Christa N. Brunnschweiler and Erwin H. Bulte. The resource curse revisited and revised: A tale of paradoxes and red herrings. *Journal of Environmental Economics and Management*, 55(3):248-264, May 2008.

[30] Erwin Bulte and Richard Damania. A note on trade liberalization and common pool resources. *Canadian Journal of Economics*, 38(3):883-899, August 2005.

[31] Francesco Caselli and Wilbur John Coleman. On the theory of ethnic conflict. July 2002.

[32] Graciela Chichilnisky. North-south trade and the global environment. *American Economic Review*, 84(4):851-74, September 1994.

[33] Jai-Young Choi and Eden S. H. Yu. Gains from trade under variable returns to scale. *Southern Economic Journal*, 50(4):979-992.

[34] Colin W Clark. Profit maximization and the extinction of animal species. *Journal of Political Economy*, 81(4):950-61, July-Aug. 1973.

[35] Colin W. Clark and Gordon R. Munro. The economics of fishing and modern capital theory: A simplified approach. *Journal of Environmental Economics and Management*, 2(2):92-106, 1975/12.

[36] C.W. Clark. *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*. Wiley, New York, 1990.

[37] Paul Collier and Anke Hoeffler. On economic causes of civil war. *Oxford Economic Papers*, 50(4):563-73, 1998.

[38] Paul Collier and Anke Hoeffler. Greed and grievance in civil war. Development and comp systems, Economics Working Paper Archive at WUSTL, September 2004.

[39] Paul Collier and Anke Hoeffler. Resource Rents, Governance and Conflict. *Journal of Conflict Resolution*, 49(4):625-633, 2005.

[40] Brian R. Copeland. Strategic enhancement and destruction of fisheries and the environment in the presence of international externalities. *Journal of Environmental Economics and Management*, 19(3):213-226, 1990.

[41] Brian R. Copeland and M. Scott Taylor. Trade, spatial separation, and the environment. *Journal of International Economics*, 47(1):137–168, February 1999.

[42] Brian R. Copeland and M. Scott Taylor. Free trade and global warming: a trade theory view of the kyoto protocol. *Journal of Environmental Economics and Management*, 49(2):205–234, March 2005.

[43] C. Cramer. Homo economicus goes to war: Methodological individualism, rational choice and the political economy of war. *World Development*, 30:1845-1864, November 2002.

[44] Pedro DalBo and Ernesto DalBo. Workers, warriors and criminals: Social conflict in general equilibrium. Working papers, Brown University, Department of Economics, 2005.

[45] Richard Damania. Trade and the political economy of renewable resource management. Adelaide University Discussion Paper 0046, 2000.

[46] Richard Damania and E. Barbier. Lobbying, trade and renewable resource harvesting. CIES Discussion Paper 0114, 2001.

[47] Richard Damania and Arnab Gupta. The political economy of resources and development in india. Adelaide University, http://www.economics.adelaide.edu.au/workshops/doc/_guptaresources6.pdf.

[48] Paul F. Diehl and Nils Peter Gleditsch, editors. *Environmental Conflict*. Westview Press, Boulder, CO, 2001.

[49] Jonathan Eaton and Arvind Panagariya. Gains from trade under variable returns to scale, commodity taxation, tariffs and factor market distortions. *Journal of International Economics*, 9(4):481-501, November 1979.

[50] Ibrahim Elbadawi and Nicholas Sambanis. How much war will we see? explaining the prevalence of civil war. *Journal of Conflict Resolution*, (46), 2002.

[51] Paavo Eliste and Per G. Fredriksson. Environmental regulations, transfers, and trade: Theory and evidence. *Journal of Environmental Economics and Management*, 43(2):234-250, March 2002.

[52] Ali Emami and Richard S Johnston. Unilateral resource management in a two-country general equilibrium model of trade in a renewable fishery resource. *American Journal of Agricultural Economics*, 82(1):161–72, February 2000.

[53] Wilfred J Ethier. Decreasing costs in international trade and frank graham's argument for protection. *Econometrica*, 50(5):1243-68, September 1982.

[54] James D. Fearon. Primary commodity exports and civil war. *Journal of Conflict Resolution*, 49(4):483-507, 2005.

[55] James D. Fearon and David D. Laitin. Ethnicity, insurgency, and civil war. *American Political Science Review*, 97:75-90, February 2003.

[56] Hanne Fjelde. Natural resources, quality of government and civil conflict. Department of Peace and Conflict Research, Uppsala University, http://www.pcr.uu.se/publications/other_pub/isapaper_fjelde.pdf.

[57] Per G. Fredriksson and Jakob Svensson. Political instability, corruption and policy formation: the case of environmental policy. *Journal of Public Economics*, 87(78):1383-1405, August 2003.

[58] Michelle R. Garfinkel and Stergios Skaperdas. Economics of conflict: An overview. Working papers, University of California-Irvine, Department of Economics, 2006.

[59] Dmitriy Gershenson and Herschel I. Grossman. Civil conflict: Ended or never ending? *Journal of Conflict Resolution*, 44(6):807-821, December 2000.

[60] Nils Petter Gleditsch. Armed conflict and the environment: A critique of the literature. *Journal of Peace Research*, (35):381-400, 1998.

[61] Nils Petter Gleditsch, Peter Wallensteen, Mikael Eriksson, Margareta Sollenberg, and Havard Strand. Armed conflict 1946-2001: A new dataset. *Journal of Peace Research*, 39(5):615-637, 2002.

[62] Francisco M. Gonzalez. Effective property rights, conflict and growth. *Journal of Economic Theory*, in press.

[63] Daniel V. Gordon and K. Klein. *Sharing Common Property Resources: The North Atlantic Cod Fishery*, chapter 13 in M. Dore and T. Mount (eds.). Global Environmental Economics, Oxford: Blackwell, 1999, pages 285-300.

[64] Gene M Grossman and Elhanan Helpman. Protection for sale. *American Economic Review*, 84(4):833-50, 1994.

[65] Herschel I Grossman. A general equilibrium model of insurrections. *American Economic Review*, 81(4):912-21, 1991.

[66] Herschel I. Grossman. Choosing between peace and war. Nber working papers 10180, National Bureau of Economic Research, December 2003.

[67] Kirk Hamilton and Michael Clemens. Genuine savings rates in developing countries. *World Bank Economic Review*, 13(2):333-56, May 1999.

[68] Rgnvaldur Hannesson. Renewable resources and the gains from trade. *Canadian Journal of Economics*, 33(1):122-132, February 2000.

[69] Havard Hegre and Nicholas Sambanis. Sensitivity analysis of empirical results on civil war onset. *Journal of Conflict Resolution*, 50(4):508-535, 2006.

[70] Hvard Hegre. Disentangling democracy and development as determinants of armed conflict. *The World Bank*, 2003.

[71] Horst Herberg and Murray C. Kemp. Some implications of variable returns to scale. *Canadian Journal of Economics*, 2(3):403-415, August 1969.

[72] Roland Hodler. The curse of natural resources in fractionalized countries. *European Economic Review*, 50(6):1367-1386, August 2006.

[73] Thomas F. Homer-Dixon. *Environment, Scarcity, and Violence.* Princeton University Press, Princeton N.J., 1999.

[74] Louis Hotte, Ngo Van Long, and Huilan Tian. International trade with endogenous enforcement of property rights. *Journal of Development Economics*, 62(1):25-54, June 2000.

[75] Macartan Humphreys. Natural Resources, Conflict, and Conflict Resolution: Uncovering the Mechanisms. *Journal of Conflict Resolution*, 49(4):508-537, 2005.

[76] Naoto Jinji. International trade and terrestrial open-access renewable resources in a small open economy. *Canadian Journal of Economics*, 39(3):790-808, August 2006.

[77] Daniel Kaufmann, Aart Kraay, and Massimo Mastruzzi. Governance matters iv: Governance indicators for 1996-2004. World Bank Policy Research Working Paper 3630, 2005.

[78] Michael T Klare. *Resource Wars: The New Landscape of Global Conflict*. Metropolitan Books: New York, 2001.

[79] Duncan Knowler. A review of selected bioeconomic models with environmental influences in fisheries. *Journal of Bioeconomics*, 4(2):163-181, May 2002.

[80] Paul Krugman. Space: The final frontier. *Journal of Economic Perspectives*, 12(2):161-74, Spring 1998.

[81] Rafael La Porta, Florencio Lopez-de Silanes, Andrei Shleifer, and Robert Vishny. Law and finance. *Journal of Political Economy*, 106(6):1113-1155, December 1998.

[82] Rafael La Porta, Florencio Lopez-de Silanes, Andrei Shleifer, and Robert Vishny. The quality of government. *Journal of Law, Economics and Organization*, 15(1):222-79, April 1999.

[83] Philippe Le Billon. The political economy of war: What relief agencies need to know. Humanitarian Practice Network paper 33, Overseas Development Institute, London, 2000.

[84] Philippe Le Billon. Buying peace or fuelling war: the role of corruption in armed conflicts. *Journal of International Development*, 15(4):413-426, 2003.

[85] Paolo Mauro. Corruption and growth. *The Quarterly Journal of Economics*, 110(3):681-712, August 1995.

[86] Paolo Mauro. Corruption and the composition of government expenditure. *Journal of Public Economics*, 69(2):263-279, 1998/6/1.

[87] John W. Maxwell and Rafael Reuveny. Resource scarcity and conflict in developing countries. *Journal of Peace Research*, 37(3):301-322.

[88] Kenneth E. McConnell and Ivar E. Strand. Benefits from commercial fisheries when demand and supply depend on water quality. *Journal of Environmental Economics and Management*, 17(3):284-292, November 1989.

[89] E. Miguel, Satyanath Shanker, and Ernest Sergenti. Economic shocks and civil conflict: An instrumental variables approach. *Journal of Political Economy*, 112(4):725-753, August 2004.

[90] Hugh M Neary. A comparison of rent-seeking models and economic models of conflict. *Public Choice*, 93(3-4):373-88, 1997.

[91] Jolle Noailly, Cees A. Withagen, and Jeroen C.J.M. van den Bergh. Spatial evolution of social norms in a common-pool resource game. Technical report, Fondazione Eni Enrico Mattei, May 2005.

[92] Akira Okubo and Simon A. Levin. *Diffusion and Ecological Problems: Modern Perspectives*. Springer, New York, 2001.

[93] Benjamin A. Olken. Corruption perceptions vs. corruption reality. NBER Working Papers 12428, National Bureau of Economic Research, Inc, 2006.

[94] Ola Olsson. Conflict diamonds. *Journal of Development Economics*, 82(2):267-286, March 2007.

[95] Arvind Panagariya. Variable returns to scale in production and patterns of specialization. *American Economic Review*, 71(1):221-30, March 1981.

[96] Lopez Ramon. The environment as a factor of production: The effects of economic growth and trade liberalization. *Journal of Environmental Economics and Management*, 27(2):163-184, September 1994.

[97] Lopez Ramon and Siddhartha Mitra. Corruption, pollution, and the kuznets environment curve. *Journal of Environmental Economics and Management*, 40:137-150, 2000.

[98] Michael Renner. *Fighting For Survival: Environmental Decline, Social Conflict, and the New Age of Insecurity*. Worldwatch Institute, Washington D.C., 1996.

[99] Michael Renner. The anatomy of resource wars. *Worldwatch Institute*, (162), 2002.

[100] Rafael Reuveny and John W. Maxwell. Conflict and Renewable Resources. *Journal of Conflict Resolution*, 45(6):719-742, 2001.

[101] Douglas Rivers and Quang H. Vuong. Limited information estimators and exogeneity tests for simultaneous probit models. *Journal of Econometrics*, 39(3):347-366, November 1988.

[102] Dani Rodrik, Arvind Subramanian, and Francesco Trebbi. Institutions rule: The primacy of institutions over geography and integration in economic development. *Journal of Economic Growth*, 9(2):131-165, 2004.

[103] J. Ron. Paradigm in distress? primary commodities and civil war. *Journal of Conflict Resolution*, 49(4):443-450, 2005.

[104] Michael L. Ross. The political economy of the resource curse. *World Politics*, 51(2):297-322, 1999.

[105] Michael L. Ross. What do we know about natural resources and civil war? *Journal of Peace Research*, 41(3):337-356, 2004.

[106] P.F. Sale, M.J. Butler IV, A.J. Hooten, J.P. Kritzer, K.C. Lindeman, Y. J. Sadovy de Mitcheson, R.S. Steneck, and H. van Lavieren. Stemming decline of the coastal ocean: Rethinking environmental management. United nations university policy brief, UNU-INWEH, 2008.

[107] James N. Sanchirico and James E. Wilen. Bioeconomics of spatial exploitation in a patchy environment. *Journal of Environmental Economics and Management*, 37(2):129-150, March 1999.

[108] James N. Sanchirico and James E. Wilen. Dynamics of spatial exploitation: A metapopulation approach. *Natural Resource Modeling*, 14(3):391-418, 2001.

[109] James N. Sanchirico and James E. Wilen. Optimal spatial management of renewable resources: matching policy scope to ecosystem scale. *Journal of Environmental Economics and Management*, 50(1):23-46, July 2005.

[110] C-E. Schulz. Trade policy and ecology. *Environmental and Resource Economics*, 8:15-38(24), 1996.

[111] Carl-Erik Schulz. Trade policy and ecology. *Environmental and Resource Economics*, 8(1):15-38, 1996.

[112] Stergios Skaperdas. An economic approach to analyzing civil wars. Technical report, Department of Economics, University of California, Irvine, May 2005.

[113] Anders Skonhoft and Jan Tore Solstad. The political economy of wildlife exploitation. *Land Economics*, 74(1):16-31, feb 1998.

[114] Robert M Solow. The economics of resources or the resources of economics. *American Economic Review*, 64(2):1–14, May 1974.

[115] Inc. The PRS Group. International country risk guide (table 3b), c, 1984-Present. http://www.prsgroup.com.

[116] Jeremy M. Weinstein. Resources and the information problem in rebel recruitment. *Journal of Conflict Resolution*, 49(4):598-624, 2005.

[117] Martin L. Weitzman. Why the far-distant future should be discounted at its lowest possible rate. *Journal of Environmental Economics and Management*, 36(3):201-208, November 1998.

[118] James E. Wilen. Renewable resource economists and policy: What differences have we made? *Journal of Environmental Economics and Management*, 39(3):306-327, 2000.

[119] James E. Wilen. Spatial management of fisheries. *Marine Resource Economics*, 19:7-19, 2004.

[120] Anastasios Xepapadeas and William Brock. Optimal control and spatial heterogeneity: Pattern formation in economic-ecological models. Working papers, Fondazione Eni Enrico Mattei, July 2005.

[121] xxx. World development indicators. *World Bank, Washington, DC.*, 2006.