Conflict and Production: An Application to Natural Resources

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Abstract

We present a Stackelberg model of conflict, in which contestants have limited endowments to be put in two separate sectors, thus incorporating salient features of many conflicts. The model is applied to the case of conflict over natural resources. Consistent with amounting empirical evidence regarding a so-called "resource curse", we find that the relation between conflict intensity and resource rents is non-monotonous, and that the economy's income growth rate may be negatively affected by resource abundance.

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1 Introduction

Conflict is a phenomenon that in one form or the other tackles the life of us all, be it a competition between colleagues over a promotion at work, a fight between members of our family or village, or violent conflicts on a big scale, such as civil wars and disputes between states. Conflict adversely affects the economic, physical and emotional well-being of many people, and so it is unsurprising that research into the ultimate and proximate causes of such events has become a lively field in economics. Following significant theoretical advances in the early 1990s on the 'economics of conflict' in general (e.g., Hirshleifer [1991a], Hirshleifer [1991b], Hirshleifer [1995], Grossman [1994], Grossman and Kim [1995]), the field has developed and now encompasses econometric work and more focussed theoretical analyses. The structure of conflict games is always of a similar nature. Two agents have the choice between productive or contesting (unproductive) activity. Their objective is to maximize their utility. Utility is derived from two sources: (1) A share of total production, aided by the productive inputs of both agents, goes to each of the agents. (2) The allocation of the contested prize [1] depends on the relative contesting efforts supplied by each agent. An increase in the prize makes contesting activity more attractive to both contenders. That is, productive activity aids both agents, whereas the payoff of (unproductive) contest activity only accrues to the agent undertaking it.

So far the literature has neglected some specific salient features of contests. In this paper we consider a situation in which (1) the two contenders are not of equal standing, but one has a first mover advantage (i.e. a *Stackelberg game* is treated), and (2) competitors have *limited endowments* to be put in two *separate* sectors [2]. Endowments can be allocated either to productive (benevolent) or contesting (malevolent) activity. Due to limited resources, an agent that decides to be productive, has less endowment left to put in contesting activity and vice versa. We are not aware of work that captures all of the above in one model. Yet, there are many real-life situations to which a model with these features is applicable.

For one, think of a situation in which co-workers compete for a certain position in an organization. The utility of each agent is given by the status of the position he is holding and his income. The contested prize is the status and prestige connected with the position. The Stackelberg leader is the incumbent, i.e. the person holding the position at the present

[1] In many conflict models the contested prize is total production in the economy - an assumption different to what we consider in this paper.

[2] That is, we consider a situation of conflict over an *exogenous* contested prize.

moment. He has a first-mover advantage, for example due to better access to information. The follower is the person that longs for the position. Both have the choice to allocate their total available effort (which is their working time, i.e. 8 hours a day) to either contributing to the organization's output (and thus increasing their salary [3]) or engage in unproductive "mobbing" of the other person in order to acquire the position. The given example captures conflict among individuals.
The model also applies to situations with "institutionalized" conflict, for example between the ruler and the people of a country. They compete for control over a flow of rents, that stems from development aid or natural resource rents. But conflict is not inevitable – rebelion may be deterred by the threat of force, or the people may be pacified by 'public investments'. Following important work by Azam [1995], Azam [2001] and also Azam and Mesnard [2003], we assume that the ruler (as a Stackelberg leader) may invest in defense to quell opposition, or that it may 'buy the peace' by providing a productivity-enhancing public good (also see Grossman [1994], and for empirical evidence, see Azam et al. [1996]). On the other hand the people (the Stackelberg follower) spend their (limited) effort either on productive working or on stealing rents.

The contribution of the paper is three-fold. First, we present a general conflict model that incorporates salient features in many conflict situations. That is we model a Stackelberg game in which both contenders have limited endowments to put into contesting or productive activities. In this paper we focus on the second example given above, in particular we consider a situation of conflict among a ruler and the people over natural resource rents. The second contribution of the paper is thus to examine the relationship between the amount of resource rents and conflict activities. We find that a hump-shape relation characterizes this relationship. Conflict intensity is low at very low and very high levels of resource wealth. It peaks at intermediate levels. Third, we trace out the effect of resources on economic performance. We find that resource wealth may induce a "convergence from above". That is, resource rich countries may overshoot at times, converging back to their "normal" income level as resource rents dry up.

Our model outcomes are consistent with empirical evidence. Recent work by Collier and Hoeffler [2004] suggests that opportunities for rebelion (sometimes referred to as the 'greed motive') are an important driver of conflict. This corroborates analyses implicating natural resources as a cause of civil war (e.g. Collier and Bannon [2003], Ross [2004a], Ross [2004b],

[3]The organization's output is allocated among the agents in the form of salaries.

Fors and Olsson [2004]). A robust empirical finding is a non-monotonous relationship between the amount of resources and the extent of conflict activity in an economy (Collier and Hoeffler [1998]). Conflict intensity does not, as one might expect at first sight, increase linearly with the amount of resource rents, but peaks at intermediate values. We reproduce this finding in our model, and thereby provide a theoretical underpinning of the empirical result.

In addition, empirical work also associates natural resources with low or even negative economic growth rates (e.g. Sachs and Warner [1997]), the link between resources and conflict possibly represents another manifestation of what has become known as the "curse of natural resources". There is empirical evidence that the resource curse is due to some "convergence from above" of countries. Overshooting at some point, resource rich countries converge back to adequate income levels as time passes (Rodriguez and Sachs [1999]). We find a similar result in our theoretical model, whereas the causal mechanism is different from the one in Sachs and Rodriguez [4].

The paper is organized as follows. In Section 2, we present the general conflict model using the interpretation of conflict over resource rents. We explicitly look at the role of resource rents in a Stackelberg model of conflict, recognizing the inherent difference of the ruler and the people respectively. By this we differ from recent other theoretical contributions on conflicts and natural resources. Hodler [2006] develops a model in which institutional quality is endogenously determined. Natural resources decrease productive activity via two channels; they increase the incentive to fight, and decrease the incentive to work because conflict erodes institutions (i.e. weakens property rights). Wick and Bulte [2006] trace out the effects of the resource's pointiness on appropriative actions in the economy. Both of these works consider contenders to be of equal standing, which may be inappropriate in the context of conflicts between unequals, such as a ruler and the people. In Section 3 we turn to a concrete specification and are thereby able to trace out the optimal appropriative effort decisions of both agents as a function of resource rents in Section 4. In the following sections, we turn to applications of this result. Section 5 considers the relationship between conflict intensity and resource wealth. This is done by considering the comparative static properties of the results of section 4 with respect to the amount of resource rents. In Section 6, we take a "dynamic view". Resource rents may well vary over time, thus the results of Section 4 lend themselves to a dynamic analysis as well (Caselli and Coleman [2006]). While assuming that

[4] Sachs and Rodriguez argue that if resource money is invested domestically rather than abroad, this leads to investment and consumption booms at home, which in turn increase domestic output. Thus, resource rich countries live beyond their means for a while, before falling back to "normal" income levels.

resource earnings fall over time, we trace out the effect on income levels and growth. Until recently, the focus of the economic conflict literature was on static games. While there are obviously examples where a static approach is defendable, we believe that the link between a time-varying natural resource stock and conflict calls for a dynamic view. Recently several papers have come out that analyze conflict in a dynamic context (e.g. Grossman and Kim [1996]; Gonzalez [2005]; Gonzalez [2006]; Maxwell and Reuveny [2005]; Mehlum and Moene [2006]; Grossman and Mendoza [2003]), but we are unaware of existing analyses that keep track of an evolving exhaustible resource stock as the prize. Focusing on its income level, we follow the fate of a single economy over time as the resource stock is being depleted – distinguishing between different "phases of development". Finally, Section 7 concludes.

2 The general model

As mentioned we focus on the application on natural resources in this paper. As we go on, we thus interpret the model in these terms.

The two agents in the model are the ruler and the people or the population of a country. Resource rents are fueled into the economy, and thus provide the incentive to engage in contesting activity[5]. Both groups in society have a certain "budget" they can allocate to two possible activities. The people allocate their effort to stealing and production, so they potentially turn into a rebel force if contesting the rent is profitable. The ruler has a budget which he can use to provide a productivity-enhancing public good or he can allocate to the contest. Moreover, the ruler taxes the people's production (or otherwise benefits from it). Following Azam, we assume the ruler and people play a Stackelberg game, with the government as the Stackelberg leader[6]. But our specification of the contest process is different from Azam: the ruler can, as a first mover, at some cost choose how much of the rent he wants to fully secure. The rest is open for contesting, and may be grabbed by the people. This means the government controls the size of the contested prize.

[5]Think of a situation where the government receives resource rents as a sort of usage fee paid by an (international) firm extracting the resource. Then there are different approaches to capture the notion that the people may wrestle those rents from the government.
First, following Tornell and Lane [1999], one may view the public budget as a common pool from which various groups try to secure a share. Second, one can develop a model where rebels fight to control part of the resource stock, so that they themselves become the residual claimant of some of the resource rents generated by the international firm. Third, and closest to the specification that we have in mind, one can think of a model where 'rebels' steal part of the output generated by the firm, and sell it elsewhere. For example, in Nigeria there is widespread diversion of pumped-up oil that is subsequently traded. The degree to which such theft is possible is, of course, determined by enforcement and hence is subject to choices made by the government. It does not matter whether the rebels take the physical output (oil, diamonds, or another commodity) or money - one can easily be converted into the other.

[6]We believe governmental and rebels' contesting efforts are inherently different. The government has a natural monopoly on violence, which makes it the natural leader in this game. For rebels on the other hand it is much harder to credibly commit to violent action. Thus, they are the follower.

2.1 The Setup

We assume a general production function given by $F(\phi, W)$ with $\frac{\partial F}{\partial \phi} > 0$ and $\frac{\partial F}{\partial W} > 0$, where ϕ denotes a productivity enhancing public good and W is the working effort provided by the people. The production function is assumed to be multiplicatively separable and is denoted by $F(\phi, W) = f_1(\phi) f_2(W)$, where $\frac{\partial f_1}{\partial \phi} > 0$ and $\frac{\partial f_2}{\partial W} > 0$. Production benefits both the people and the ruler who either taxes production (in case of a formal sector) or benefits from bribes and kickbacks (in case of an informal sector). To hone in on the key tradeoff between production and fighting we treat the tax (or bribe) rate as constant and exogenous, τ.

The proceedings of the resource sector are also split between the two parties. The split is determined by the respective contesting efforts. We call $G(R, D, E)$ the "grabbing function", where R denotes the flow of resource rent poured into the economy, D is the governmental defense effort and E is the people's stealing effort. This function denotes how much of the resource is grabbed by the people given (R, D, E). Again, the logical signs apply, i.e. $\frac{\partial G}{\partial R} > 0, \frac{\partial G}{\partial D} < 0, \frac{\partial G}{\partial E} > 0$. A multiplicatively separable specification is given by $G(R, D, E) = g_1(R) g_2(D) g_3(E)$, with $\frac{\partial g_1}{\partial R} > 0$, $\frac{\partial g_2}{\partial D} < 0$ and $\frac{\partial g_3}{\partial E} > 0$. Accordingly $[R - G(R, D, E)]$ is the share of the rent flowing to the ruler. The "rebel leader" allocates effort across the two possible activities, so that for the people the following budget constraint is relevant: $W + E \leq N$, where N is total effort available. Similarly, the ruler has a budget Q that he divides between the contest and public good provision: $D + \phi \leq Q$.

2.2 Contesting efforts as strategic substitutes or complements?

Since the people are the follower in the Stackelberg game, we consider, by backwards induction, first their maximization problem. It is given by:

$$\max_{E,W} \quad \pi^P = (1 - \tau) F(\phi, W) + G(R, D, E) \tag{1}$$

where τ is the tax rate

$$\text{s.t.} \qquad W + E \leq N = 1 \tag{2}$$

$$E \geq 0 \tag{3}$$

$$W \geq 0 \tag{4}$$

Note that we normalize the people's endowment, N, to 1. Budget constraint (2) will always be fulfilled with equality (since π^P is strictly increasing in both arguments, E and W), so

that "wasting" any effort is never optimal[7].

The optimal stealing effort of the people, E^*, is defined by

$$\underbrace{\frac{\partial G(R, D, E^*)}{\partial E}}_{MB} = \underbrace{-(1-\tau)\frac{\partial F(\phi, 1-E^*)}{\partial E}}_{MC}. \tag{5}$$

The LHS denotes the marginal benefit of an increase in E, the RHS the marginal cost. If rebels devote more effort to stealing, they can secure more of the resource (MB). On the other hand, it implies less time for working, so that income from production decreases (MC). How does rebel stealing effort E respond to an increase in defense, D? To examine whether contest activities are strategic substitutes or complements, we investigate how the MB and the MC change with an increase in D.

Increasing defense effort D has two counteracting effects on optimal stealing effort. First, there is a direct negative effect because there is less to steal for the people (the unsecured rent, i.e. the *potential* prize for the rebels, becomes smaller). But there is an indirect effect as well. If the government increases defense effort, less resources are left to be invested in the public good. This implies that the productivity of effort in production falls, so that the opportunity cost of stealing decreases. This effect works to increase the optimal stealing effort of the people. Hence, both the marginal cost and the marginal benefit of E decrease, as D goes up. Which of the two decreases more determines the sign of $\frac{\partial E^*}{\partial D}$. If the marginal benefit decreases more than the marginal cost (the case that will be discussed later) then $\frac{\partial E^*}{\partial D} < 0$, and (E, D) are strategic substitutes. For other functional forms it could be the case that $\frac{\partial E^*}{\partial D} > 0$, i.e. (E, D) are strategic complements[8].

So far we have assumed that the production function as well as the grabbing function are multiplicatively separable, with the logical signs. If one of them were additive, this would have straightforward effects on our results. In particular:

[7] This also implies that $\frac{\partial f_2}{\partial E} = \frac{\partial f_2}{\partial W}\frac{\partial W}{\partial E} = -\frac{\partial f_2}{\partial W}$.

[8] More formally, $\frac{\partial F}{\partial E}(< 0)$ denotes how much output is lost if there is one less unit of work effort. In the notation introduced above $\frac{\partial F}{\partial E} = -\frac{\partial f_2}{\partial W} f_1(\phi)$. We are interested in $\frac{\partial^2 F}{\partial E \partial D}$, which is equal to $\frac{\partial^2 F}{\partial W \partial \phi} = \frac{\partial f_2}{\partial W}\frac{\partial f_1}{\partial \phi} > 0$. More output is lost, the higher ϕ. The opportunity costs of stealing increase with the amount of public good provided. Therefore we know that $\frac{\partial MC}{\partial D} = -(1-\tau)\frac{\partial^2 F}{\partial W \partial D} < 0$. Similarly, $\frac{\partial G}{\partial E}(> 0)$ denotes how much more can be grabbed if stealing effort is increased by one unit. Employing the definition of the grabbing function given above we find $\frac{\partial G}{\partial E} = g_1(R)g_2(D)\frac{\partial g_3}{\partial E}$. We find that $\frac{\partial^2 G}{\partial E \partial D} = g_1(R)\frac{\partial g_2}{\partial D}\frac{\partial g_3}{\partial E} < 0$. Thus we know $\frac{\partial MB}{\partial D} = \frac{\partial^2 G}{\partial E \partial D} < 0$. The marginal return of stealing effort is lower, if D is high. An extra appendix discussing these issues at greater length is available upon request.

- If the production function is additive in its inputs, then $\frac{\partial^2 F}{\partial E \partial D} = 0$. Note that this implies that there is no possibility for the ruler to lure the people into production, i.e. "buying the peace" is not possible. In this case (E, D) are strategic substitutes.

- If the grabbing function is additive in its inputs, then $\frac{\partial^2 G}{\partial E \partial D} = 0$. Here the strategy of "sheer force" does not work. People are not "scared away" by high governmental defense effort. Thus (E, D) are strategic complements.

The respective contesting efforts (E, D) might be complements or substitutes, depending on the functional forms chosen. That is, high governmental defense effort can either drive people away from stealing natural resources and push them into the manufacturing sector, or it can lead to the opposite, since high government expenditure on defense means very little investment in productivity enhancing public goods (because the government has limitations on how much it can spend). This in turn lowers the opportunity cost for stealing of the people, i.e. they tend to steal more. As we would like to go one step further, we next turn to a concrete specification of the model. The robustness of the results with respect to other functional specifications is discussed as we go along.

3 An example of a specified model

In this section we discuss the results of the model given specific functional forms. In particular we assume manufacturing output to be given by $F(\phi, W) = (1 + \phi)(1 + W)$. [9] The grabbing function (i.e. the amount of the resource grabbed by the people given the size of the resource stock and the fighting inputs) is assumed to be $G(R, D, E) = ZE^{\alpha}$ where, as we will see later, Z is the undefended or potential rent for the rebels: $Z = R(1 - D^{\gamma})$. Here, α and γ are parameters measuring effectiveness of the peasants' contest effort. We assume $\alpha = \frac{1}{2}$ and $\gamma = 1$.[10]) The amount of rent grabbed is increasing in the contest effort of the population and decreasing in the contest effort of the ruler.

3.1 The People's problem

The people are the follower in the Stackelberg game. Given policy choices by the government (D, ϕ) and using the specification introduced above, we can solve for their reaction function

[9] We assume a production function linear in its inputs for mathematical ease. The results typically carry over to nonlinear specifications. To see this consult the extra appendix available upon request.

[10] Numerical simulations show that the presented results do not change qualitatively for other values of α and γ (both ≤ 1 of course). That is, our mathematical simplification of $\alpha = \frac{1}{2}$ and $\gamma = 1$ is only for mathematical ease, and does not drive the results.

by maximizing their utility as given by (1)-(4). Optimizing, we find:

$$E^* = \left[\frac{Z}{2(1-\tau)(1+\phi)}\right]^2. \tag{6}$$

3.2 The government's problem

The government in our model is a selfish ruler that, like the people, is only interested in its own income. The government receives income via resource rents and taxation of production. It can implement policies that raise productivity in manufacturing or allocate effort to defense to secure part of the rent flow. The former policy raises the tax base, which is a direct effect. In addition, it increases the opportunity cost of stealing effort for the rebels. This is an indirect benefit, because it raises the share of uncontested resource rents falling back into the hands of the ruler (see below).

The problem of the government is the following:

$$\begin{aligned}
\max_{D,\phi} \quad \pi^G &= \tau F(\phi, W^*) + R - G(R, D, E^*) && (7)\\
&= \tau(1+\phi)(1+W^*) + [R - Z(E^*)^{\frac{1}{2}}],\\
\text{where} \quad E^* &= \left[\frac{Z}{2(1-\tau)(1+\phi)}\right]^2, && (8)\\
W^* &= N - E^*, && (9)\\
\text{and} \quad Z &= R(1-D). && (10)\\
s.t. \quad D + \phi &\leq Q \geq 1, && (11)\\
0 \leq D &\leq 1, && (12)\\
\phi &\geq 0. && (13)
\end{aligned}$$

Note that (11) is always fulfilled with equality, as wasting any effort is never optimal for the government (the objective function is increasing in both ϕ and D).

Consistent with our specification for the rebels, we assume a multiplicative function for securing resource rents: $R \cdot D$. Depending on the choice of D, a fraction of the rent is potentially available for the rebels: $Z = R - R \cdot D = R(1-D)$. The rebels grab a fraction $R(1-D)E^{\frac{1}{2}}$, leaving the remainder for the ruler (because it is too expensive to steal). Note that for an interior solution $D^* < 1$ must hold [11]. Below we show that this condition is always satisfied. That is, it is never optimal for the government to defend *all* of the resource.

[11] Here we assume $Q \geq 1$. Thus, in principle it is *possible* for the government to defend all of the resource. Otherwise, if we allowed for $Q < 1$, the ruler could not, even if he devoted all his resources to defense, secure *all* the resource. We do not want to impose this exogenously. Nevertheless, this arises as an endogenous result as we go on.

3.3 Strategic interaction

Since the government is the Stackelberg leader it faces the people's response as an additional constraint. Upon substituting $Z = R(1-D)$ and (11) in (6), we obtain the people's reaction function:

$$E^* = \left[\frac{R(1-D)}{2(1-\tau)(1+Q-D)}\right]^2. \tag{14}$$

It is readily verified that the government's and rebel force's contest effort levels are strategic substitutes[12]. Raising D both lowers the prize available for the peasants (discouraging stealing) and the opportunity costs of stealing [13], but the former unambiguously dominates the latter. Formally note that

$$\frac{\partial E^*}{\partial D} = -E^{1/2}\left[\frac{RQ}{(1-\tau)(1+Q-D)^2}\right] < 0. \tag{15}$$

The conflict literature finds that conflict levels may be both strategic substitutes or complements, i.e. the sign of $\frac{\partial E^*}{\partial D}$ is generally ambiguous (see for example Addison et al. [2002] or Azam [1995]). In section 2 we showed that both cases are possible in our model setup, (E, D) may be strategic substitutes as well as strategic complements. With the chosen specification we can unambiguously sign the impact of the ruler's on the people's choice. The government is able to "scare away" the people.

4 Results

In this section we characterize optimal choices of the Stackelberg leader and follower as a function of the amount of rents R in the economy.

4.1 Optimal defense effort of the government - Characterizing D^*

We first trace out the behavior of D^*. The first order condition of the ruler is given by [14]

$$\frac{\partial \pi^G}{\partial D} = \underbrace{\frac{\partial F(D^*)}{\partial E}\frac{\partial E^*}{\partial D}}_{A} + \underbrace{\tau\frac{\partial F(D^*)}{\partial D}}_{B} - \underbrace{\frac{\partial G(D^*)}{\partial D}}_{C} = 0. \tag{16}$$

An increase in defense effort has three effects on the profits of the government. First, it changes the rebels' optimal stealing effort (and hence production effort)(A). Second, it leaves the economy with a lower level of the public good, decreasing manufacturing output

[12] This unambiguity is a result of the functional forms assumed.

[13] An increase in D comes at the cost of a decrease in ϕ, because the ruler has a limited endowment. Once he puts more of his effort in defense, less is left for the public good. As a result productivity in the manufacturing sector is lower, and thus the opportunity cost of stealing decreases.

[14] To arrive at this result we employ the envelope theorem. An additional appendix showing the derivations is available upon request.

(B). Third, it secures more of the resource for the government directly (C)[15, 16] .

Plugging in the concrete specification yields

$$\frac{\partial \pi^G}{\partial D} = \frac{2-\tau}{4(1-\tau)^2}\left[\frac{R^2(1-D)(1+2Q-D)}{(1+Q-D)^2}\right] - 2\tau. \tag{17}$$

Note that $\frac{\partial \pi^G}{\partial D} = 0$ gives us an intractable quadratic equation in D. For a clean representation of the results, we trace out the qualitative behaviour of D^* via an indirect way. In the appendix we show that the objective function of the government is always concave in D. Therefore there are only two qualitatively different forms of the objective function that may emerge.

Evaluated at $D = 0$ it could be the case that $\frac{\partial \pi^G}{\partial D}_{D=0} < 0$ with the objective function monotonically decreasing in D. Obviously this translates into an optimal D of 0; $D^* = 0$ always. Alternatively, we could have that $\frac{\partial \pi^G}{\partial D}_{D=0} > 0$ (with the slope decreasing thereafter). This translates into an optimal D greater than 0, $D^* > 0$. Formally, the slope of π^G in the point $D = 0$ is given by:

$$\frac{\partial \pi^G}{\partial D}_{D=0} = -2\tau + \frac{2-\tau}{4(1-\tau)^2}\left[\frac{R^2(1+2Q)}{(1+Q)^2}\right]. \tag{18}$$

The second term on the RHS of (18) is increasing in R. So for sufficiently large values of R we find that $\frac{\partial \pi^G}{\partial D}_{D=0} > 0$ and $D^* > 0$. But as R decreases, defense effort is no longer worthwhile for the ruler. Denote $\overline{R}$ as the threshold value for the rent flow that warrants defensive effort (i.e. for $R < \overline{R}$, $D^* = 0$). This threshold value is given by:

$$\overline{R} = 2(1-\tau)(1+Q)\sqrt{\frac{2\tau}{(2-\tau)(1+2Q)}}. \tag{19}$$

Summarizing, for $R > \overline{R}$ we know that $D^* > 0$, and for $R < \overline{R}$ it is the case that $D^* = 0$. This suggests that D^* decreases as R goes down. Indeed, by differentiating the FOC (implicitly defining the optimal D) with respect to R, we find:

$$\frac{\partial D^*}{\partial R} = \frac{(1-D)(1+Q-D)(1+2Q-D)}{RQ^2} > 0. \tag{20}$$

Equation (20) implies that optimal defense effort of the government declines as R falls. Above we identified various costs and benefits associated with raising D, and (20) illustrates

[15] Intuitively, one might argue that we have "forgotten" one effect. Since the optimal stealing effort of the people changes as a response to an increase in defense, this also has an effect on the resource income of the ruler. This effect can be neglected though (as a result of the envelope theorem)

[16] Note that when $\tau = 0$ (the case of a purely informal economy, as for example considered in Marcouiller and Young [1995]) there is no negative effect of an increase in D (given (E, D) are strategic substitutes as is the case in our specified model). In this case the ruler does not provide any public good $\phi^* = 0$.

that the net marginal benefits of increasing defense effort are falling as the flow of rents dries up. This makes intuitive sense[17]. In the appendix we derive two further results about the optimal allocation of effort by the government: (i) the function relating resource rents to conflict effort is concave, and (ii) the ruler will never defend all the resource (i.e. $D^* < 1$). This latter result implies also that it is never optimal for the government to allocate its entire endowment to conflict ($D^* < Q$).

4.2 Optimal stealing effort of the rebels - characterizing E^*

Having characterized the path of optimal behaviour of the ruler we now proceed by solving for the people's response. We know that:

$$E^* = \left[\frac{R(1-D)}{2(1-\tau)(1+Q-D)}\right]^2. \tag{21}$$

The effect of increasing the inflow of rents on the allocation of effort is a priori unclear because of the intervening response by the government. We can write

$$\frac{\partial E^*}{\partial R} = \frac{(E^*)^{\frac{1}{2}}}{1-\tau}\frac{\partial X}{\partial R}, \tag{22}$$

$$\text{where} \quad X = \frac{R(1-D)}{1+Q-D}. \tag{23}$$

Then the sign of $\frac{\partial E^*}{\partial R}$ is given by the sign of $\frac{\partial X}{\partial R}$, where

$$\frac{\partial X}{\partial R} = \frac{1}{(1+Q-D)^2}[\underbrace{\underbrace{(1-D)(1+Q-D)}_{A} - \underbrace{R(1+Q-D)\frac{\partial D^*}{\partial R}}_{B}}_{\text{Bounty Effect}} + \underbrace{\underbrace{R(1-D)\frac{\partial D^*}{\partial R}}_{C}}_{\text{Public Good Effect}}]. \tag{24}$$

The term in brackets is made up of a "bounty effect" and a "public good effect". The first part reflects that increasing R raises the stakes in conflict – there is more to fight over (effect A). However, an increase in R also triggers an increase in D (for $R > \overline{R}$), which

[17] Note that this result is robust to the choice of functional forms, i.e. it is also valid for many other functional specifications of the production as well as the grabbing function. To see this intuitively, let us look at what happens to the *marginal benefits* and *marginal costs* of governmental defense D, when R increases.
First note that the *marginal cost* of D (as given by B in equation (16)) decreases in R.
Second, let us look at the *marginal benefits*. They are made up of two components. Given (E, D) are strategic substitutes, an increase in governmental defense effort affects the ruler's payoff positively through two different channels: (1) an increase in defense secures the ruler more of the resource (C in equation (16)); (2) when governmental defense is high, people work more (A in equation (16)). How are these two components affected by an increase in R?
For (1), as long as the grabbing function is multiplicative, the marginal product of defense increases in R. This is to say that it is easier for the government to defend, if there is a lot of resources. For (2), if the production function is *linear* in W, the marginal product of the people in the manufacturing sector is independent from the amount of work provided.
Then, the marginal benefit of D unambiguously increases with R, so that $\frac{\partial D^*}{\partial R} > 0$ always.
Consult the extra appendix available upon request, for a more formal treatment of this discussion.

in turn lowers the bounty accessible for the people (effect B). The bounty effect appears a priori ambiguous, but in the appendix we show that it is always negative (i.e. works to decrease E). In addition, the increase in D leads to a reduction in the public good, so that the public good effect in the expression above is always positive: it works to increase E (effect C). The next question, then, is whether the bounty or public good effect dominates, and governs the path of E. For our model, we can show that $\frac{\partial E^*}{\partial R} < 0$ holds, or that the bounty effect dominates (see appendix)[18].

Here a *de*crease in R induces a sufficiently large decrease in D to imply a rise in $R(1-D)$ (i.e. in the bounty). This effect is strong enough to offset the counteracting public good effect, and thus people increase their stealing effort as R decreases.

Note that two of the described effects (effects B and C) drop out when $\frac{\partial D^*}{\partial R} = 0$. Therefore a complete description of the path of E^* is as follows:

$$\frac{\partial E^*}{\partial R} = \begin{cases} -\frac{(E^*)^{\frac{1}{2}}(1-D)}{(1-\tau)Q} < 0 \ : \ R > \overline{R} \\ \frac{(E^*)^{\frac{1}{2}}(1-D)}{(1-\tau)(1+Q-D)} > 0 \ : \ R \leq \overline{R} \end{cases} \tag{25}$$

In the appendix we show that $E^*(R)$ is convex in the range where $R > \overline{R}$ and concave where $R \leq \overline{R}$.

Since the people only have one unit of effort available, we cannot a priori rule out corner solutions. Formally, a more complete description of E is as follows:

$$E^* < 1 \ \Leftrightarrow \ R - 2(1-\tau)(1+Q) < D(R - 2(1-\tau)), \tag{26}$$

and

$$E^* = 1 \ \Leftrightarrow \ R - 2(1-\tau)(1+Q) \geq D(R - 2(1-\tau)). \tag{27}$$

So that we find

$$\text{If} \quad R > 2(1-\tau), \text{ then } E^* < 1 \Leftrightarrow D > T(R), \text{ and} \tag{28}$$

$$\text{if} \quad R < 2(1-\tau), \text{ then } E^* < 1 \Leftrightarrow D < T(R), \tag{29}$$

where $T(R) = \frac{R-2(1-\tau)(1+Q)}{R-2(1-\tau)}$. The function $T(R)$ provides the threshold level of defense.

[18] For a more general discussion on the path of E^* consult the extra appendix available upon request from the authors. There we show that both $\frac{\partial E^*}{\partial R} < 0$ and $\frac{\partial E^*}{\partial R} > 0$ are generally possible.

Note that

$$\text{If } R > 2(1-\tau), \text{ then} \qquad \lim_{R \longrightarrow \infty} T(R) = 1 \quad \text{and} \quad \lim_{R \longrightarrow 2(1-\tau)} T(R) = -\infty. \tag{30}$$

$$\text{If } R < 2(1-\tau), \text{then} \qquad \lim_{R \longrightarrow 0} T(R) = 1 + Q \quad \text{and} \quad \lim_{R \longrightarrow 2(1-\tau)} T(R) = \infty. \tag{31}$$

Corner solutions for E^* can be ruled out by assuming $D^*(R_{max}) > T(R_{max})$, where R_{max} is the highest level of R considered [19].

We are not interested in dealing with corners here, so this is what we assume throughout the paper [20].

4.3 Summary: The paths of D^* and E^*

In the preceding section we have found the paths of D^* and E^* as a function of R. These trajectories, for sufficiently large resource stocks ($R > \overline{R}$), can be summarized in a picture [21]:

——— Insert Figure 1 about here ———

Note that Figure 1 is drawn for *decreasing* R.

Next we apply these results to two particularly interesting questions concerning the role of natural resources. We first look at the relationship between resource rents and conflict intensity. Second, we take a dynamic view. We put our (until now static) model in a dynamic framework and are thus able to follow the fate of a single economy over time paying special attention to the trajectory of income.

[19] For $R < 2(1-\tau)$, we know that $T(R) > (1+Q)$. Furthermore we know that $2(1-\tau) < \overline{R}$, as defined by equation (21), and that for $R < \overline{R}$, $D^* = 0$. That is, condition (31) is always fulfilled.
If $R > 2(1-\tau)$ then $T(R) < 0$ for $R < \check{R} = 2(1-\tau)(1+Q)$. Also we know that $\overline{R} < \check{R}$. And finally it is true that $\frac{\partial T(R)}{\partial R} > 0$. All of this together gives us that the assumption $D^*(R_{max}) > T(R_{max})$ is sufficient to rule out corners.

[20] What would happen if the above condition were not satisfied, and thus a corner solution would eventuate? E^* could hit a corner for high values of R, if at some point $D^*(R) < T(R)$. Then the ruler realizes in this range of R values the people do not react to his defense, but just choose $E^* = 1$. In this case his optimization problem is the following $max_D\ \tau(1+Q) + D(R-\tau)$. This makes perfect sense when one acknowledges the fact that now the ruler only has to take into account the direct effects of his increase in defense (so he can disregard any effects his choice has on the working/stealing effort of the people). An increase in D will on the one hand secure the ruler more of the resource, but on the other hand decrease the public good, lowering his income from the manufacturing sector. If $R > \tau$ (i.e. the positive effect of D on resource income dominates the induced reduction of manufacturing output), the ruler will set D as high as possible, $D^* = D^*(R)$, as characterized by the FOC (16). Otherwise, if $R < \tau$ (i.e. the negative effect of D overweighs), he will choose D^* as low as possible, which here means $D^* = 0$.

[21] A sufficient, though not necessary, condition for the two curves to cross is given by $R_{max} > \widehat{R}$, where $\widehat{R}$ is derived in the appendix.

5 A hump-shape of conflict intensity

In this section we look at a cross-section of countries all endowed with a different degree of resource wealth, and investigate the differing conflict experiences our model suggests. We then relate our theoretical results to empirical evidence by Collier and Hoeffler [1998].

5.1 Conflict Intensity

From Figure 1, we see that when resource rents are large (Section I), the ruler and the people fight over control of the rents. The ruler has a first-mover advantage, and secures a large share of the rent (crowding out the rebels). If the flow of rents is smaller, incentives for the ruler are different. He provides less conflict effort, and more productivity-enhancing public goods instead. Since D is lower, the rebels' respond with a higher contest effort. If rental payments are below the threshold value $\overline{R}$ (Section II), the rents are "too small" to warrant government defense. The ruler provides no defense at all, and the optimal allocation of effort by the rebels is exclusively governed by the amount of rents fueled in the economy. At $R = \overline{R}$, the comparative statics result of rebel conflict effort with respect to stock size switches sign, and rebels' stealing effort is now decreasing when R becomes smaller. When there is no resource, i.e. $R = 0$ (Section III), both groups concentrate their effort on manufacturing, that is the government sets $\phi = Q$ and the rebels provide $W = N$.

We now have all the ingredients to characterize conflict intensity as a function of rents R. Just like there are different ways to measure the intensity of conflict in reality, there are also different ways to capture conflict intensity in stylized models. One convenient and straightforward definition of conflict intensity, C, is as follows:

$$C = min(D^*, E^*). \tag{32}$$

This representation captures the fact that it takes two to wage a war. Even if one party puts in a lot of effort, and the other does not, then no conflict arises. It postulates that relatively "even" conflicts are more intense than uneven ones (holding aggregate conflict effort constant), and captures that intensity increases if both parties allocate more effort to conflict. These are all desirable features.

From Figure 1 it is evident that the relation between conflict intensity and resource abundance is non-monotonous for our specified model[22]. In particular, the relation between

[22] As we discussed in section 4.2, it could also be the case that optimal stealing effort of the people is decreasing in R. Then conflict intensity is decreasing in the amount of rents.

intensity and abundance is characterized by an inverted U shaped relationship. To verify this, move from "left" to "right" in Section I in Figure 1, keeping track of $\min(D^*, E^*)$. At high R, $D^* > E^*$, but after the curves cross the reverse holds. The finding of an inverted U shaped relation between resources and conflict intensity is consistent with empirical work by Collier and Hoeffler [1998] and Collier and Hoeffler [2004].

In particular, Collier and Hoeffler demonstrate in their papers a non-monotonous relationship between resources (measured as primary good exports) and civil war occurrence. They define civil wars as events that cost more than 1000 deaths per year. This is rather consistent with our measure of conflict intensity. At high levels of R, our measure of intensity is low as D is small and the threshold (of civil war occurrence) may not be reached. No civil war occurs. At intermediate levels of R, our measure of intensity is higher. If it crosses the threshold, our model predicts the occurrence of a civil war. Finally, at low levels of R, the measure for intensity falls below the threshold, so our model again predicts no civil war. That is, our model predicts a civil war only at intermediate values, and none at very low or very high levels of resource wealth. This matches Collier and Hoeffler's findings.

They propose the underlying mechanism is the following: Resource wealth has two counteracting effects on the probability of civil war so that the overall effect is ambiguous, and the hump-shape evolves. On the one hand, more resources allow the government to increase their military expenditure. Thus the government can suppress potential opposition and the probability of a civil war decreases. On the other hand, more resources increase the potential prize for rebel groups if they manage to capture the state, thereby increasing the risk of conflict. Our general equilibrium set-up, with a given span of control, allows for a different explanation. That is, accounting for alternative occupations and investment opportunities for the ruler also yields the inverted U.

5.2 An alternative conflict measure – the economic costs of conflict

An economic measure of conflict intensity measures how much production is foregone due to conflict activity. We define

$$C^E = GDP^N - GDP^C = \underbrace{R + F(Q)}_{GDP^N} - \underbrace{R - F(Q, D, E)}_{-GDP^C}, \tag{33}$$

where the superscript E stands for *economic*, N for *no conflict*, and C for *conflict*. GDP is given by the income from the resource, R, plus income from the manufacturing sector $F(\cdot)$. By assumption, in a "no-conflict economy" the population puts *all* its effort into working. In a "conflict economy" on the other hand, income from production depends on the contesting

decisions of the agents. We refer to C^E as the *economic costs of conflict* in what follows.

Using our specific functional forms, the costs of conflict are given by the following expression:

$$C^E = R + 2(1+Q) - R - (1+Q-D)(2-E) = 2D + E(1+Q-D). \tag{34}$$

Note that if $R < \overline{R}$ (since then $D^* = 0$), the economic costs of conflict are given by

$$C^E = E(1+Q). \tag{35}$$

In general, the evolution of this measure of conflict intensity is given by

$$\frac{\partial C^E}{\partial R} = -\left[\frac{\partial F}{\partial D}\underbrace{\frac{\partial D^*}{\partial R}}_{>0} + \frac{\partial F}{\partial E}\underbrace{\frac{\partial E^*}{\partial R}}_{<0}\right], \tag{36}$$

which is, using the functional specifications,

$$\frac{\partial C^E}{\partial R} = \underbrace{(2-E)\frac{\partial D^*}{\partial R}}_{A} + \underbrace{(1+Q-D)\frac{\partial E^*}{\partial R}}_{B}. \tag{37}$$

If $R > \overline{R}$ the effect of an increase in R is ambiguous. If R is high, the government puts forth more defense effort, i.e. provides less of the public good, decreasing manufacturing output. This increases the costs of conflict (effect A in equation (37)). On the other hand, people steal less when R is high, providing more working effort and thereby increasing manufacturing output. This decreases the costs of conflict (effect B in equation (37)). Increases in R may thus increase or decrease the costs of conflict. Note that for $R < \overline{R}$, we find that $\frac{\partial C^E}{\partial R} > 0$. That is, for $R < \overline{R}$, the economic costs of conflict are decreasing, as R goes down. Thus, whenever $\frac{\partial C^E}{\partial R}|_{R^{max}} < 0$, we also find a hump-shape of this - economic - conflict measure.

6 A dynamic view

We now put the results of section 4 in a dynamic framework. Assuming that resource rents fall over time, we trace out the time-trajectories of actions of the agents. We follow the fate of a single economy over time and focus on the implications for economic performance.
The assumption that resource rents decrease over time has many justifications. In particular this time path is the result of an intertemporally optimizing firm, that has some market power, extracting a finite and non-replenishable resource stock.

The timing of the game is as follows: At the beginning of the period, the foreign firm

extracts some of the resource stock. The optimal extraction rate is time-dependent, and in every period t given by X_t. The firm pays a usage fee $R_t = \mu X_t$ to the owner of the resource (the ruler)[23]. These are the resource rents fueled into the economy, triggering actions of the two agents[24]. For any R_t, we can find the optimal actions of the ruler (optimal defense effort D_t^*, implying optimal provision of the public good ϕ_t^*) and the people (optimal stealing effort E_t^*, implying optimal working effort W_t^*)

6.1 The foreign firm's problem

A foreign firm extracts a given non-renewable resource stock such as a mineral or oil deposit. The firm is hired by the *de jure* resource owner (the ruler) and works independently from the rest of the economy. It maximizes the present value of rents, of which a fixed fraction is transferred to the ruler[25]. The exact division of rents between firm and ruler is determined by a bargaining process not modeled here. The resource stock, S_t, evolves as follows over time: $\frac{\partial S_t}{\partial t} = -X_t$, and the firm pays $R_t = \mu X_t$ to the government for the right to extract X_t units of the resource at time t. Following the textbook example provided by Conrad and Clark [1987] we assume that the firm has some market power on output markets and faces a linear downward sloping inverse demand function. Optimal extraction, then, dictates the following rule:

$$X_t = \frac{a}{2}(1 - e^{r(t-T)}), \tag{38}$$

where r is the rate of interest, a is a demand parameter and T is the date of exhaustion of the resource. From (38) it is evident that $\frac{\partial X_t}{\partial t} < 0$, or the stream of rental payments becomes smaller over time. Downward sloping extraction paths are a quite robust result in Hotelling-style models, so the main results of the ensuing analysis spill over to many different specifications of the firm's problem. The time period of full depletion is defined by:

$$\int_0^T X_t dt = S_0, \tag{39}$$

where S_0 denotes the initial stock of the resource. While the ruler and people are contesting the current flow of rents, since the rate of extraction is time-dependent, so is behavior. The time path of resource extraction implies a time path for the choice variables of the agents.

[23]Note that the firm could also be required to pay part of its *profits* to the ruler as a usage fee. Then $R_t = \mu p(X_t)X_t$. Optimal extraction is sloping downwards as demanded by the Hotelling rule. Since the firm is a monopolist, $p(X)$ is sloping upwards. As long as profits are decreasing over time, all the dynamic behaviour of the model, as it is discussed in what follows, stays the same.

[24]So in any time period t three decisions are taken: first, the firm decides on extraction, then the ruler decides on defense effort, and last the people decide on optimal stealing effort.

[25]That is, the flow of rents is set by the firm and assumed independent of (strategic) actions by the ruler or people. An example would be offshore drilling for oil and gas – a production activity that proceeds for all intents and purposes independently of the rest of the economy.

6.2 The people's and the government's problem re-visited

Putting the model in a dynamic framework, requires to give the problems of the people and the government intertemporal character.

The intertemporal maximization problem of the people is the following:

$$\max_{E_t, W_t} U^P = \int_{t=0}^{\infty} e^{-rt} \pi_t^P dt \tag{40}$$

$$\text{where} \quad \pi_t^P = (1-\tau)F(\phi_t, W_t) + G(R_t, D_t, E_t) \tag{41}$$

subject to constraints (2)-(4).

The government's intertemporal utility maximization problem is given by:

$$\max_{D_t, \phi_t} U^G = \int_{t=0}^{\infty} e^{-rt} \pi_t^G dt \tag{42}$$

$$\text{where} \quad \pi_t^G = \tau F(\phi_t, W_t^*) + R_t - G(R_t, D_t, E_t^*) \tag{43}$$

subject to the constraints (8)-(13).

While the model is dynamic by nature of the depletion process (i.e., R_t varies over time), neither the government nor the people invest or disinvest in assets. The lack of intertemporal spillover effects implies that the dynamic model reduces to a series of static optimization problems (see Dockner et al. [2000]), which have been treated as such in the preceding sections [26]. This allows us to readily flesh out the evolution of conflict intensity and output *over time*, using the results of Section 4. Figure 1 therefore shows the time-trajectories of appropriative actions[27]. The combination of the trajectories defines three separate development phases for an economy endowed with an exhaustible resource.

In Phase I the resource stock and associated flow of rents are large. Both agents put forth much appropriative effort. Over time, the flow of rents becomes smaller, until it becomes too small to make it worthwhile for the ruler to go on defending it (Phase II). When rents are rather low, the government finds it in its own best interest to allow the rebels to steal some of the resource. Rather than fighting to prevent it, the government invests in public goods to tease the rebels into manufacturing. Over time, an increasing number of rebels succumbs to this temptation, and conflict effort gradually disappears from the economy. Finally when all of the resource is used (Phase III), there is no contesting anymore and both agents put all their endowment into production. In the absence of accumulation of capital or knowledge, as assumed here, the economy stops growing.

[26] Thus, by assuming that both agents have an exogenously given capacity to undertake activities, the given maximization problems boil down to a series of static optimization problems.

[27] As resource rents decrease over time, one can picture time t on the x-axis now.

6.3 The trajectory of income

Income in the economy is defined as the sum of rental payments and the value of manufacturing. In light of the recent controversy about the relation between income (growth) and resource abundance – the so-called 'resource curse' – it is instructive to consider the trajectory of income over the three stages in more detail. Phase III, where the resource is depleted, is trivial in this respect: aggregate income is simply given by $GDP_{III} = 2(1+Q)$ and it is unchanging over time ($\frac{\partial GDP}{\partial t} = 0$).
But dealing with the other phases is more challenging.

For example, in phase II GDP is given by

$$GDP_{II} = R + 2(1+Q) - \frac{R^2}{4(1-\tau)^2(1+Q)}. \tag{44}$$

This is a quadratic function in R that reaches its maximum at some level of R, that we denote as R^*. A change in R has two counteracting effects in phase II, which together yield this form of GDP_{II}. When rental payments go down, there is a direct and negative effect on aggregate income. However, lower rents induce a decrease in E, so working effort of the people goes up which tends to raise GDP. For higher R values, the working effort effect dominates and GDP goes up when R falls. In contrast, for lower levels of R, the direct resource effect dominates and GDP decreases when R falls.

How does the presence of a flow of resource rents affect an economy's income? The effect is typically ambiguous. Denote income in a non-resource economy as GDP^N. For sufficiently low values of R, $R < \widetilde{R}$, resource flows provide an impetus for income: $GDP_{II} > GDP^N$. But we also find that income growth rates are adversely affected by rental payments. A complete characterization depends on the value of the tax rate τ. Three possible cases can emerge. (1) For "low $(1-\tau)$" we find $R^* < \widetilde{R} < \overline{R}$. This implies GDP_{II} will initially be below GDP^N, but as extraction proceeds income will increase and eventually $GDP_{II} > GDP^N$ (when $R < \widetilde{R}$). Income further increases, but then starts to fall. In final stages the resource-economy will experience a negative growth rate, until $R = 0$ is reached. The resource economy's income approaches the non-resource economy's income from above. (2) For "intermediate levels" of $(1-\tau)$ we find that $R^* < \overline{R} < \widetilde{R}$, and $GDP_{II} > GDP^N$ throughout. Depending on R, the resource economy experiences positive or negative growth and eventually, as above, GDP_{II} approaches GDP^N from above. (3) For "high levels" of $(1-\tau)$ we find $\overline{R} < R^* < \widetilde{R}$, so that $GDP_{II} > GDP^N$, as above. But, unlike the case above, it is always the case that income in the resource economy is decreasing over time. For

a formal treatment and a graphical representation of the above results, consult the appendix.

Taken together, these possibilities suggest that the behavior of GDP_{II} for a range of R values is the same (notably, this holds when R is not too great – which is the situation that will eventually emerge in *all* societies after extraction has proceeded sufficiently long). Rental payments will (i) increase income levels, but (ii) result in negative growth rates. This is in line with empirical evidence. Rodriguez and Sachs [1999] promote the idea of income convergence from above, and empirical work by de Gregorio and Bravo-Ortega [2005] is also consistent with this result. Note that we obtain this result without resorting to Matsuyama-style positive externalities in manufacturing (Matsuyama [1992]).

The dynamics in stage I are too complex to solve analytically, but yield ambiguous results both with respect to income levels and growth rates. This is easily demonstrated for the simplest case where the tax rate τ approaches zero – the case where the informal economy is thriving and the ruler has virtually no possibility to claim part of the value added generated. For $\tau \to 0$, it is evident from (17) that then $\frac{\partial \pi^G}{\partial D} > 0$, so that the ruler should (given our specification) optimally set $D = 1$ (and, hence, $\phi = Q - 1$). All of the resource is defended in this case, and thus $E^* = 0$, so that aggregate income is simply $GDP_t = R_t + 2Q$. Upon comparing this to the income level in the absence of resource extraction (i.e. $GDP_t^N = 2(1 + Q)$), it is evident that resources raise income levels in the economy as long as $R > 2$ holds. Income will be lower if the reverse condition holds. The result for the growth rate is simpler, $\frac{\partial GDP}{\partial t} = \frac{\partial R}{\partial t}$, so that income is falling over time.

7 Conclusions

Recently, two literatures have emerged that implicate natural resource abundance as a driver of both slow economic growth and civil unrest. We argue that these two phenomena are not independent, and propose a unified model that links resource rents to the allocation of effort between production and conflict. Just like most literature on the topic (see for example Collier and Hoeffler [1998]), we use a flow variable to measure resource wealth of a country. This is in line with the extensive literature on the resource curse, where it has been found that it is usually resource *flows* (most commonly used in the literature is the share of primary goods exports in total exports) and not resource *stocks* that inhibit a country's development (Ding and Field [2004], Stijns [2001]).

The objective of the paper is two-fold: (1) Our model provides insights into the different

conflict experiences of resource rich countries (depending on their degree of resource wealth). (2) We place conflict over resource rents in a dynamic setting. Dynamics are introduced by a time-dependent stream of rental payments from an international firm to the government. These 'contestable rents' determine optimal behaviour of the agents in the model. Since rents vary over time, so does behaviour, and we can distinguish between different phases in the development process of a sufficiently resource rich country. We also find that there may be qualitatively different development trajectories of countries, depending on the degree of resource richness.

Our main analytical results are consistent with empirical evidence: (1) in line with findings of Collier and Hoeffler [1998] and Collier and Hoeffler [2004] we unearth a non-monotonous relation between resources and conflict intensity, and (2) following work of Sachs and Warner [1997] and others we find that resource wealth tends to slow down growth (but may raise income levels). Note that the model can also be used to make predictions on how *new* resource discoveries might affect the (economic) fate of a country.

In the present paper we look at the role of resources in conflict. That is not to deny that there are other factors that may trigger such violent clashes, such as ethnic hostilities. The point of this paper is to show that resource rents may be one of the factors fueling a conflict. The exact way in which they do is the object of investigation.

Policy wise the model gives some hints on what to consider when *minimizing conflict activities* is the goal. Following the model there are essentially two ways to achieve minimal conflict, either take out the resource all at once, while at the same time repressing people harshly, or extracting very little at a time, so as not to trigger too much greed among the population.

Since analytical results are sometimes hard to obtain in conflict models, we had to invoke a number of simplifying assumptions to maintain tractability. The main ones, arguably, are (i) the exogenous budgets Q and N, and (ii) the simplified model set-up where we treat the tax rate as a parameter (rather than a choice variable). Relaxing these assumptions will likely involve searching for numerical solutions. But we believe the current model presents a good starting point for more detailed explorations in the future.

8 Appendix

8.1 Proofs regarding the path of D

Proof that the objective function is concave: The second derivative of the objective function is

$$\frac{\partial^2 \pi^G}{\partial D^2} = \underbrace{\frac{2-\tau}{2(1-\tau)}}_{>0}[\frac{-R^2(1+Q-D)+R^2(1-D)}{(1-\tau)(1+Q-D)^2} - \frac{-R^2(1-D)(1+Q-D)+R^2(1-D)^2}{(1-\tau)(1+Q-D)^3}] < 0 \quad (45)$$

$$\Leftrightarrow \quad -R^2(1+Q-D)^2 + R^2(1-D)(1+Q-D) < -R^2(1-D)(1+Q-D) + R^2(1-D)^2 \quad (46)$$

$$\Leftrightarrow \quad -((1+Q-D)^2 - 2(1-D)(1+Q-D) + (1-D)^2) < 0 \quad (47)$$

$$\Leftrightarrow \quad -((1+Q-D)-(1-D))^2 < 0 \quad (48)$$

$$\Leftrightarrow \quad -(Q)^2 < 0 \quad (49)$$

Therefore we know that

$$\frac{\partial^2 \pi^G}{\partial D^2} < 0 \Leftrightarrow 0 < Q^2 \quad (50)$$

which is always the case, so that we can conclude that the objective function is concave in D.

Proof that $D^*(R)$ is concave: First note that

$$\frac{\partial D^*}{\partial R} = \frac{(1-D)(1+Q-D)(1+2Q-D)}{RQ^2} = \frac{A}{RQ^2} \quad (51)$$

Then

$$\frac{\partial A}{\partial R} = (-\frac{\partial D^*}{\partial R}) \underbrace{[(1+Q-D)(1+2Q-D) + (1-D)(1+2Q-D) + (1-D)(1+Q-D)]}_{B} \quad (52)$$

We are interested in

$$\frac{\partial^2 D^*}{\partial R^2} = \frac{(-\frac{\partial D^*}{\partial R})BRQ^2 - AQ^2}{R^2Q^4} \quad (53)$$

$$= \frac{1}{R^2Q^2}\left[-\frac{\partial D^*}{\partial R}\underbrace{BR}_{>0} - \underbrace{A}_{>0}\right] < 0 \quad (54)$$

Therefore we know that $D^*(R)$ is concave in R.

Proof that the ruler will never defend all of the resource: For this consider

$$\frac{\partial \pi^G}{\partial D}|_{D=1} = \frac{2-\tau}{4(1-\tau)^2}[\frac{R^2(1-1)(1+2Q-1)}{(1+Q-1)^2}] - 2\tau = -2\tau < 0 \quad (55)$$

So it is never optimal for the government to secure all of the resource (to choose $D^* = 1$), i.e there is always something left to grab. This result also implies that the government will never find it optimal to spend all of its endowment on defending (as we assumed that $Q \geq 1$), so $D^* < Q$.

8.2 Proofs regarding the path of E

Derivation of $\frac{\partial E^*}{\partial R}$ (for $R > \overline{R}$):

- The bounty effect is always negative:

$$sgn \text{ Bounty Effect} = sgn \left[(1-D)(1+Q-D) - R\frac{\partial D^*}{\partial R}(1+Q-D) \right] \tag{56}$$

$$= sgn \left[(1+Q-D) \left[(1-D) - R\frac{(1-D)(1+Q-D)(1+2Q-D)}{RQ^2} \right] \right] \tag{57}$$

$$= sgn \left[\frac{(1+Q-D)(1-D)}{Q^2} [Q^2 - (1+Q-D)(1+2Q-D)] \right] \tag{58}$$

$$= sgn \left[\underbrace{-Q^2 + D}_{<0} \underbrace{-1+D}_{<0} \underbrace{-4Q + 3DQ}_{<0} - D^2 \right] < 0 \tag{59}$$

- The overall effect:

$$sgn \frac{\partial E^*}{\partial R} = sgn [\underbrace{\underbrace{(1-D)(1+Q-D)}_{A} - \underbrace{R(1+Q-D)\frac{\partial D^*}{\partial R}}_{B}}_{\text{Bounty Effect}} + \underbrace{\underbrace{R(1-D)\frac{\partial D^*}{\partial R}}_{C}}_{\text{Public Good Effect}}] \tag{60}$$

$$= sgn \left[\frac{1}{R} - \frac{\frac{\partial D^*}{\partial R}}{1-D} + \frac{\frac{\partial D^*}{\partial R}}{1+Q-D} \right] \tag{61}$$

$$= sgn \left[\frac{1}{R} - \frac{1}{1-D}\frac{(1-D)(1+Q-D)(1+2Q-D)}{RQ^2} + \frac{1}{1+Q-D}\frac{(1-D)(1+Q-D)(1+2Q-D)}{RQ^2} \right] \tag{62}$$

$$= sgn \left[1 + \frac{1+2Q-D}{Q^2}(-1-Q+D+1-D) \right] \tag{63}$$

$$= sgn \left[1 - \frac{1+2Q-D}{Q} \right] < 0 \tag{64}$$

since $D < 1 + Q$

Thus, one can conclude that the negative prize effect always overweighs the positive public good effect and E^* is decreasing in R, i.e. $\frac{\partial E^*}{\partial R} < 0$ for $R > \overline{R}$.

The sign of $\frac{\partial^2 E^*}{\partial R^2}$: For $\frac{\partial D^*}{\partial R} > 0$ (i.e. for $R > \overline{R}$) we find

$$\frac{\partial^2 E^*}{\partial R^2} = -\frac{1}{(1-\tau)Q}[\frac{1-D}{E^{1/2}} \underbrace{\frac{\partial E^*}{\partial R}}_{<0} - E^{1/2} \underbrace{(\frac{\partial D^*}{\partial R})}_{>0}] > 0. \tag{65}$$

For $\frac{\partial D^*}{\partial R} = 0$ (i.e. for $R \leq \overline{R}$) we find

$$\frac{\partial^2 E^*}{\partial R^2} = -\frac{1}{(1-\tau)(1+Q-D)^2} \tag{66}$$

$$\left[\frac{1}{2}((1-D)E^{-1/2}\frac{\partial E^*}{\partial R} - E^{1/2}(\frac{\partial D^*}{\partial R}))(1+Q-D) + E^{1/2}(1-D)(\frac{\partial D^*}{\partial R})\right]$$

$$= -\frac{1}{(1-\tau)(1+Q-D)^2} \tag{67}$$

$$\left[\frac{1}{2}(1-D)E^{-1/2}\frac{\partial E^*}{\partial R}(1+Q-D) - E^{1/2}(\frac{\partial D^*}{\partial R})(1+Q) - E^{1/2}(\frac{\partial D^*}{\partial R})D + E^{1/2}(1-D)(\frac{\partial D^*}{\partial R})\right]$$

$$= -\frac{1}{(1-\tau)(1+Q-D)^2} \tag{68}$$

$$\left[\frac{1}{2}(1-D)E^{-1/2}\underbrace{\frac{\partial E^*}{\partial R}}_{<0}(1+Q-D) - E^{1/2}\underbrace{(\frac{\partial D^*}{\partial R})}_{>0}D\right] < 0$$

8.3 Proofs regarding the paths of D^* and E^*

A sufficient (though not necessary) condition for the two effort paths, D^* and E^*, to cross is that R is such that

$$\frac{\partial \pi^G}{\partial D}|_{D=E^{max}} > 0. \tag{69}$$

where E^{max} is the maximum value reached by E^*:

$$E^{max} = E^*|_{R=\overline{R},D^*=0} = \frac{2\tau}{(2-\tau)(1+2Q)} \tag{70}$$

If condition (69) is fulfilled, then D^* is at some point (at least) as high as E^{max}. Knowing that $D^* = 0$ and $E = E^{max}$ at $R = \overline{R}$, the two curves must then cross at some $R > \overline{R}$. A hump-shaped conflict path emerges.

Calculations yield that the value of R where (69) holds is given by

$$\widehat{R} = \frac{2\sqrt{2\tau}(1-\tau)}{\sqrt{2-\tau}} \frac{(1+Q)(2-\tau)(1+2Q) - 2\tau}{[(2-\tau)(1+2Q) - 2\tau]^{1/2}[(2-\tau)(1+2Q)^2 - 2\tau]^{1/2}} \tag{71}$$

Whenever $R^{max} > \widehat{R}$ it is ensured that a crossing of effort paths exists.

8.4 Proofs regarding the trajectory of income

Proofs regarding Stage II:

We know

$$GDP_{II} = R + 2(1+Q) - \frac{R^2}{4(1-\tau)^2(1+Q)} \tag{72}$$

This is a concave function in R:

$$\frac{\partial^2 GDP_{II}}{\partial R^2} = -\frac{2}{4(1-\tau)^2(1+Q)} < 0 \tag{73}$$

The maximum of this function is reached at R^*:

$$\frac{\partial GDP_{II}}{\partial R} = 0 \quad \Leftrightarrow \quad 1 - \frac{2R^*}{4(1-\tau)^2(1+Q)} = 0 \tag{74}$$

And so

$$R^* = 2(1-\tau)^2(1+Q). \tag{75}$$

Income in the resource rich country is higher than income in the resource poor country (which we call GDP^N here) when $R < \widetilde{R}$. That is,

$$GDP_{II} > GDP^N \quad \Leftrightarrow \quad R + 2(1+Q) - \frac{R^2}{4(1-\tau)^2(1+Q)} > 2(1+Q) \tag{76}$$

$$R < 4(1-\tau)^2(1+Q) = \widetilde{R} \tag{77}$$

Note that $R^* < \widetilde{R}$. Plotting the three relevant levels of R as a function of $(1-\tau)$ one gets the following picture (for a given level of Q[28]):

———— Insert Figure A1 about here ————

There are three cases to be distinguished: For low levels of $(1-\tau)$ (i.e. high τ) we can see from the picture that $R^* < \widetilde{R} < \overline{R}$. For intermediate levels of $(1-\tau)$ (i.e. intermediate τ), it is the case that $R^* < \overline{R} < \widetilde{R}$. Finally for high values of $(1-\tau)$ (i.e. low τ), $\overline{R} < R^* < \widetilde{R}$. The different cases are treated verbally in the main text. Below see the graphical representation of all three scenarios:

———— Insert Figures A2, A3, A4 about here ————

[28]Note that we assume here that Q is such that the graph looks as in Figure A1, i.e. Q is not too large. If Q were "too large", not all of the ranges defined by Figure A1 exist.

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9 Figures

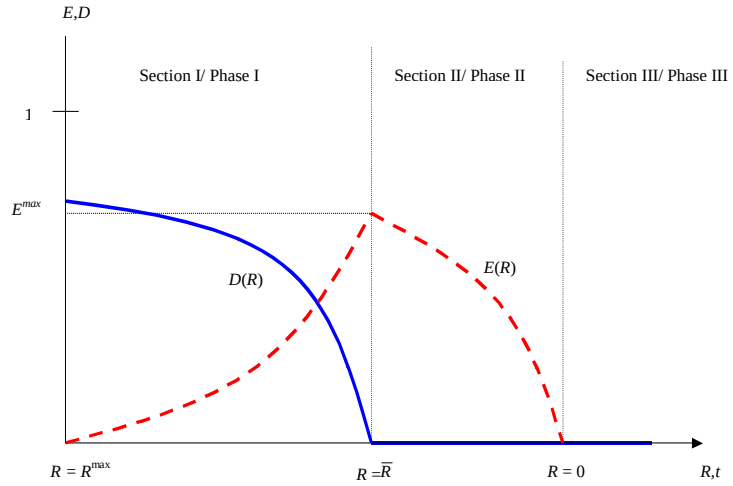

Figure 1: Conflict effort of the ruler (D, solid line) and the people (E, dashed line) as a function of the flow of rents (R)

Note that this figure is drawn for *decreasing* R. At the farthest point to the left $R = R^{max}$, and at the farthest point to the right $R = 0$. With respect to section 6 this means that one can picture time t on the x-axis.

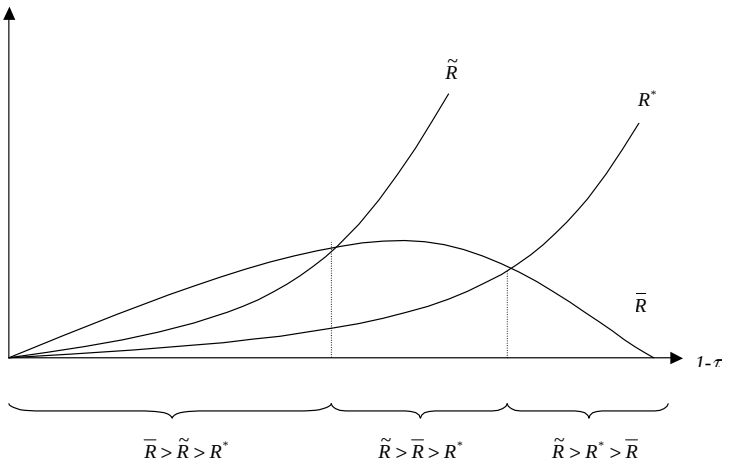

Figure A1: The three relevant levels of R plotted as a function of $(1 - \tau)$

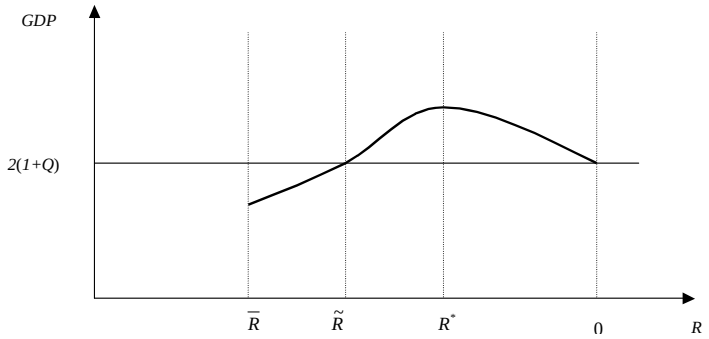

Figure A2: The trajectory of income for low $(1-\tau)$

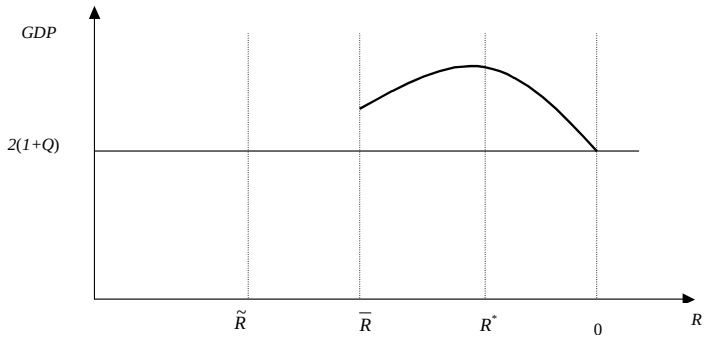

Figure A3: The trajectory of income for intermediate $(1-\tau)$

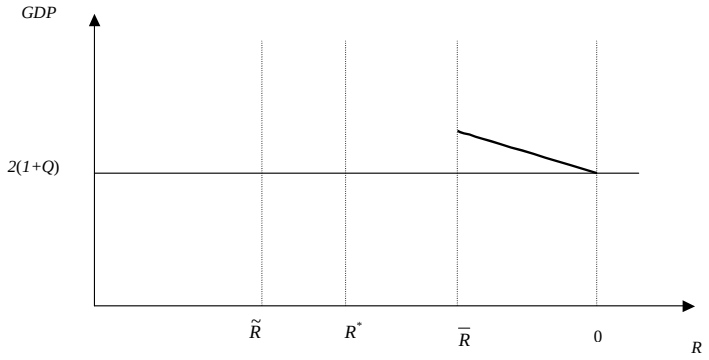

Figure A4: The trajectory of income for high $(1-\tau)$