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Political Economy of Dynamic Resource Wars

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POLITICAL ECONOMY OF DYNAMIC RESOURCE WARS

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Abstract

The political economy of natural resource extraction is analysed in three different contexts. First, if an incumbent faces a threat of being removed once and for all by a rival faction, extraction becomes more voracious, especially if the rebel faction shares rents much more than the incumbent. Second, perennial political conflict cycles are more inefficient if cohesiveness of the constitution or the partisan in-office bias is large and political instability is high. Third, resource wars are more intense if the political system is less cohesive, there is a partisan in-office bias of the incumbent, oil reserves are high, the wage is low, governments can be less frequently removed from office, and fighting technology has less decreasing returns to scale. Resource depletion in such wars is more rapacious if there is more government instability, the political system is less cohesive, and the partisan in-office bias is smaller.

Keywords: political conflict; cohesiveness; partisan bias; dynamic resource wars; contests; rapacious depletion; exploitation investment; hold-up problem

JEL codes: D81, H20, Q31, Q38

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1. Introduction

How does the presence of a large stock of natural resources and the chance of being removed from office affect government behaviour? How do political instability and the cohesiveness of political institutions affect rent grabbing and the voracity of resource depletion? How does the threat of war affect the speed of resource extraction and prices of natural resources? How are resource wars affected by the cohesiveness of political institutions, the ease by which political parties can be removed from office, and fighting technology? How do costly attempts to stay in office ('fighting') affect the probability of staying in office, the rapacity of natural resource extraction and efficiency? Our objective is to provide answers to each of these questions by analysing the political economy of natural resource extraction in three different contexts.

First, we analyse the situation where an incumbent faces a threat of being removed once and for all by a rival faction and show how this makes resource extraction voracious, especially if the risk of being removed from office is high, a small fraction of resource rents is shared with the rival faction, and the new government hands out a small fraction of rents as cohesiveness payments, and depresses exploitation investment.

Second, we analyse perennial political conflict cycles using a model of two-sided regime switches with exogenous hazard rates. We show that this induces rapacious oil depletion, especially if political cohesiveness, the partisan in-office bias is large, and governments change frequently, and we show that political instability lowers the welfare of the incumbent.

Third, we develop a political economy explanation of dynamic resource wars with the probability of a change of government depending on relative fighting intensities based on a game-theoretic model with two-sided regime switches and endogenous hazard rates. We show that resource wars are more intense if the political system is less cohesive, there is a partisan in-office bias of the incumbent, oil reserves are high, the wage is low, governments can be less frequently removed from office, and fighting technology has less decreasing returns to scale. Furthermore, oil extraction is more rapacious especially if there is more government instability, the political system is less cohesive, and the partisan in-office bias is smaller.

To get tractable closed-form solutions, we make two bold assumptions: iso-elastic demand for natural resources and zero variable extraction costs. Without risk of being removed from office, monopolistic resource extraction is then efficient and governed by the Hotelling rule (Stiglitz, 1976). These assumptions thus help to highlight the inefficiencies that follow from perennial political cycles and dynamic resource wars in a striking and analytically convenient manner.[2] In addition, we suppose that the incumbent incurs upfront costs of exploitation investment so that the initial stock of reserves is endogenous (cf., Gaudet and Laserre, 1988).[3]

Our model of one-off political risk is related to models of the effects of political uncertainty about nationalization and the speed of natural resource extraction (e.g., Long, 1975; Konrad et al., 1994; Bohn and Deacon, 2000; Laurent-Luchetti and Santaguni, 2012). Our model of the holdup problem relates to an extensive literature (e.g., Rogerson, 1992; Holmström and Roberts, 1998). Our concept of cohesiveness captures the quality of the constitution and refers to the notion that one cannot give handouts to one faction in society without also giving handouts to other factions (Besley and Persson, 2011ab). Our model of partisan political cycles relies on the incumbent giving a higher weight to utility when in office than when out of office (cf. Aguiar and Amador, 2011). This in-office bias induces an upward partisan bias in the rate of resource extraction, which is akin to the upward debt bias in the positive theory of public debt and deficits (e.g., Persson and Svensson, 1989; Alesina and Tabellini, 1990).

Our model of dynamic resource wars makes use of contest functions, familiar from the static literature on resource wars (e.g., Tullock, 1967; Hirshleifer, 1991; Skaperdas, 1996; Konrad, 2009)[4], and contributes to a recent literature on the two-way link between resource extraction and conflict (Acemoglu et al., 2012; van der Ploeg and Rohner, 2012). In contrast to earlier studies on bargaining and war between sovereign states (e.g., Powell, 1993; Skaperdas, 1992; Acemoglu et al., 2012; Caselli et al., 2015)[5], we focus on conflict over the control of natural resources within the boundaries of a state.

Although our paper is theoretical, it is worth pointing out that the cross-country empirical evidence suggests that countries with high natural exports experience more armed conflict especially in sub-Saharan Africa (e.g., Collier and Hoeffler, 2004; Ross, 2004; Fearon, 2005). This type of evidence also suggests that natural resources boost conflict, especially in societies that are ethnically polarised (e.g., Reynal-Quarol, 2002; Montalvo and Reynal-Quarol, 2005) or where ethnic cleavages and the political dominance of one group matters (e.g., Cederman and Girardin, 2007).

[2] From now on, we will refer to oil as shorthand for natural resources.
[3] We abstract from uncertainty and irreversible oil exploitation investment (Kellogg, 2014).
[4] Contest success functions have also been used to study the interstate conflicts over natural resources and its effects on trade (Garfinkel et al., 2011).
[5] Guns versus butter dilemmas and arms races have also been studied in differential game analyses of the Richardson model (e.g., Brito, 1972; Intriligator, 1975; van der Ploeg and de Zeeuw, 1991).

Giant oil discoveries around the world since 1946 turn out to increase armed conflict especially for countries that had already experienced armed conflict or coups in the previous decade (Lei and Michaels, 2014). Within-country evidence also points in this direction (e.g., Angrist and Kugler, 2008) and establishes that an exogenous increase in the world price of capital-intensive natural resources such as oil leads to more guerrilla and paramilitary attacks (Dube and Vargas, 2013). If elites act inefficient and repressive to cling to power (e.g., the blocking of railways and industrialisation by Russian and Austrian empires), resource booms raise political stakes and makes things worse but they also encourage would-be elites to contest power and fight to take control of resources (Acemoglu and Robinson, 2006). The micro evidence on interstate wars suggests that war is more likely if of two neighbouring countries one has oil and the other one does not or has oil far from the border (Caselli et al., 2015). Most of the empirical literature takes discoveries, reserves and exports of natural resources as exogenous, but evidence on cross-border strips of land suggests that discoveries and drilling are more likely on the side of the border where institutions are better and conflict is less (Cust and Harding, 2015). The fact that known subsoil resource wealth per square kilometre is 23,000 US dollar in sub-Saharan Africa compared with 105,000 US dollar globally (Collier, 2011) suggests that with improved institutions more discoveries will take place in sub-Saharan Africa and indeed this shift in the frontier of natural resource seems to be happening (Arezki, et al., 2016). The empirical evidence thus suggests, on the one hand, that natural resources increases armed conflict, and, on the other hand, that quality of institutions (including the threat of expropriation) and conflict curbs discoveries and exploitation activities. This motivates the theories of the two-way interaction between conflict and resources extraction put forward in this paper.

The outline of the paper is as follows. Section 2 analyses the effects of a one-off change in government on the rate of resource extraction and on exploitation investment. Section 3 extends this to a context of perennial political cycles. Section 4 extends this to allow for dynamic resource wars. Section 5 summarises results offers suggestions for further research.

2. One-Off Chance of a Future Regime Switch: Role of Cohesiveness

Let the incumbent A face a one-off chance of being removed from office by a rebel faction B at some unknown future date T. We suppose that A when in office offers a fraction $0 \le \tau^A \le 0.5$ of natural resource rents to the rival faction B and that B when in office offers a faction $0 \le \tau^B \le 0.5$ of rents to faction A. These fractions indicate how cohesive the factions are. In a fully cohesive society it is not possible to take rents without giving equal rents to the other faction in which case $\tau^A = \tau^B = 0.5$. In societies with poor institutions rents will be not so equally shared, however (cf. Besley and Persson, 2011a,b).[6] We suppose that the incumbent A is less cohesive than the challenger B, so that $\tau^A < \tau^B$. This is the reason why B has an interest to contest the rule of A. Let the price elasticity of oil demand be constant and marginal revenue be positive, so $\varepsilon > 1$. Oil extraction costs are zero and factions are risk-neutral. Utility is thus $U(R) = R^{1-1/\varepsilon} / (1-1/\varepsilon)$, where $R > 0$ denotes the rate of oil depletion. Welfare is the area under the demand curve, so that

$$(1) \qquad p = U'(R) = R^{-1/\varepsilon}, \quad \varepsilon > 1.$$

As marginal revenue is always finite and positive, reserves are exhausted asymptotically.

2.1. Resource depletion rates of the new government

Working backwards in time in accordance with the principle of optimality of dynamic programming, faction B once in office maximises its rent net of cohesive payments,

$$(2) \qquad \underset{R,I}{\text{Max}} \int_T^\infty (1-\tau^B(t))\, p(t) R(t)\, \mathrm{e}^{-r(t-T)}\, dt,$$

subject to the inverse demand function (1) and the oil depletion equations,

$$(3) \qquad \dot{S}(t) = -R(t),\ \forall t \ge T, \qquad \int_T^\infty R(t)dt \le S(T),$$

where S denotes the stock of oil reserves and r is the exogenous and constant market interest rate. The optimal policy requires that marginal oil revenue must equal the scarcity rent, λ, which according to the Hotelling rule must rise at a rate equal to the market interest rate, r:

$$(4) \qquad (1-\tau^B)(1-1/\varepsilon)R(t)^{-1/\varepsilon} = \lambda(t), \qquad \dot{\lambda}(t)/\lambda(t) = r, \qquad t \ge T.$$

It follows from (1) and (4) that under the new regime of faction B the price and oil depletion paths are efficient despite the country being a monopolist on world markets:

$$(5) \qquad \dot{p}(t)/p(t) = r > 0, \quad \dot{R}(t)/R(t) = -\varepsilon r < 0, \qquad t \ge T,$$

Using (5) in the oil depletion equations (3), we obtain $R(t) = \varepsilon r S(t)$ and thus

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[6] Our model can be reformulated to capture the risk of expropriation of an international oil company if one sets $\tau^A = 0$ and interprets $1-\tau^B$ as the confiscation tax and h as this risk.

$$\text{(6)} \qquad \begin{aligned} &R(t) = \varepsilon r e^{-\varepsilon r(t-T)} S(T), \qquad S(t) = e^{-\varepsilon r(t-T)} S(T) \le S(T), \\ &p(t) = e^{r(t-T)} \left(\varepsilon r S(T)\right)^{-1/\varepsilon}, \qquad \forall t > T. \end{aligned}$$

The optimal depletion and price paths follow Hotelling paths and are constrained efficient (conditional on $S(T)$). They do not depend on the cohesiveness transfer rate, τ^B, because this is effectively a lump-sum tax. Substituting (6) in (2), we get B's welfare at time T:

$$\text{(7)} \qquad V^B\left(S(T), \tau^B\right) \equiv \int_T^\infty (1-\tau^B) R(t)^{1-1/\varepsilon} e^{-r(t-T)} dt = (1-\tau^B)(\varepsilon r)^{-1/\varepsilon} S(T)^{1-1/\varepsilon}.$$

where $V^B(.)$ denotes B's (undiscounted) value function. The welfare for the incumbent faction at the time after it has lost office consists of cohesiveness payments only and is given by

$$\text{(8)} \qquad V^A\left(S(T), \tau^B\right) \equiv \tau^B (\varepsilon r)^{-1/\varepsilon} S(T)^{1-1/\varepsilon}, \quad \forall t \ge T.$$

2.2. Resource depletion rates and exploitation investment by the incumbent

Given future expected cohesiveness payments, the incumbent A has to choose initial exploitation investment, I, and the extraction path to maximise its expected welfare,

$$\text{(9)} \qquad \underset{R,I}{\text{Max}}\ \text{E}\left[\int_0^\infty (1-\tau^A) p(t) R(t) \mathrm{e}^{-rt}\, dt + e^{-rT} V^A\left(S(T), \tau^B\right)\right] - qI,$$

subject to the inverse oil demand function (1), the oil depletion equations,

$$\text{(10)} \qquad \dot{S}(t) = -R(t), \forall 0 \le t \le T, \quad S(0) = S_0 > 0, \qquad \int_0^T R(t) dt \le S_0 - S(T),$$

the oil exploitation investment schedule,

$$\text{(11)} \qquad S_0 = \Omega(I) = \omega_0 I^\omega, \quad \Omega' > 0, \Omega'' < 0, \quad \omega_0 > 0,\ 0 < \omega < 1,$$

and the probability that it is removed from office in the interval ending at time *t*,

$$\text{(12)} \qquad \Pr(T \le t) = 1 - \exp(-ht), \forall t \ge 0, \quad h \ge 0,$$

where q is the exogenous price of oil exploitation investment. Concavity of $\Omega(.)$ ensures decreasing returns to exploitation investment. The exponential distribution (12) with constant hazard rate *h* implies that the probability that A is *not* removed from office before time *t* is $\Pr(T > t) = \exp(-ht)$. The conditional probability that removal from office has not taken place during an interval of duration *s* is independent of time, i.e., $\Pr(T > s + t | T > s) = \Pr(T > t), \forall s, t \ge 0.$ Both the expected duration and the standard deviation of A's term of office equal the inverse of the hazard rate, $1/h$.

The HJB equation for the dynamic programming problem of the incumbent A is (see appendix 1)

$$(13) \qquad rV(S,\tau^A,\tau^B) = \underset{R}{\text{Max}}\left[(1-\tau^A)p(R)R - V'(S,\tau^A,\tau^B)R\right] - h\left[V(S,\tau^A,\tau^B) - V^A(S,\tau^B)\right],$$

where $V(S,\tau^A,\tau^B)$ denotes the value function (excluding its outlay on exploitation investment) for A when it still is in office and $V^A(S,\tau^B)$ is the value function for A when it has lost office. The optimality condition for the rate of oil extraction is

$$(14) \qquad (1-\tau^A)(1-1/\varepsilon)p(t) = V'\left((S(t),\tau^A,\tau^B\right) \quad \Rightarrow \quad R(t) = \left(\frac{V'\left((S(t),\tau^A,\tau^B\right)}{(1-\tau^A)(1-1/\varepsilon)}\right)^{-\varepsilon}, \quad 0 \le t \le T.$$

Upon substitution of (14) into the HJB equation (13), we obtain

$$(15) \qquad rV(S,\tau^A,\tau^B) = \frac{(1-\tau^A)^{\varepsilon}}{\varepsilon}\left(\frac{V'(S,\tau^A,\tau^B)}{1-1/\varepsilon}\right)^{1-\varepsilon} - h\left[V(S,\tau^A,\tau^B) - V^A(S,\tau^B)\right].$$

To solve (15), we use the method of undetermined coefficients. We thus postulate $V(S,\tau^A,\tau^B) = KS^{1-1/\varepsilon}$, substitute it, use (8), verify, and solve for K from the algebraic equation:[7]

$$(16) \qquad \frac{(1-\tau^A)^{\varepsilon}}{\varepsilon}K^{1-\varepsilon} + h\tau^B(\varepsilon r)^{-1/\varepsilon} = (r+h)K.$$

From (14) and (1), we then have the oil price and depletion rate during A's incumbency:

$$(17) \qquad p(t) = KS(t)^{-1/\varepsilon}/(1-\tau^A) \quad \text{and} \quad R(t) = (1-\tau^A)^{\varepsilon}K^{-\varepsilon}S(t), 0 \le t < T.$$

Defining $L \equiv \left((1-\tau^A)/K\right)^{\varepsilon}$ and solving for the time paths from (17) and (3), we obtain

$$(18) \qquad p(t) = e^{Lt/\varepsilon}(LS_0)^{-1/\varepsilon}, \quad R(t) = Le^{-Lt}S_0, \quad S(t) = e^{-Lt}S_0, \quad 0 \le t < T.$$

[7] Since $\varepsilon > 1$, the left-hand side of equation (16) falls with K and asymptotically tends to a non-negative value. The right-hand side increases linearly in K, so equation (16) yields a unique, positive solution for K.

Proposition 1: *Once the incumbent has once and for all been removed from office, the oil price rises at the rate r and the oil depletion rate and reserves decline at the rate εr. Before the change of office, the oil depletion rate and reserves decline at the rate L > εr and the oil price rises at the rate L/ε > r with the time paths given by (17). A higher probability of being removed from office, less cohesive rent sharing by the incumbent and the anticipation of less cohesiveness payments once out of office leads to more voracious oil depletion (higher L) and lower welfare of the incumbent (lower K).*

Proof: see appendix 2.

If the new government B does not share any rents at all with A, i.e., $\tau^B = 0,$ then $V^A(S,0) = 0$ and (15) implies that the incumbent A raises its discount rate, *r*, with the hazard of being removed from office, *h*. Indeed, (16) gives $K = (1-\tau^A)\left[\varepsilon(r+h)\right]^{-\varepsilon}$ and $L = \varepsilon(r+h) > \varepsilon r,$ so that the speed of oil extraction is boosted by the hazard of being removed from office. In general, oil extraction of the incumbent will be less voracious if it gets cohesiveness payments when removed from office from the new government B. In particular, if both factions share their oil rents equally with the rival faction, $\tau^A = \tau^B = 0.5,$ (16) gives $K = 0.5(\varepsilon r)^{-1/\varepsilon}$ and $L = \varepsilon r,$ so extraction is efficient.

If there is no political risk, *h* = 0, (16) gives $K = (1-\tau^A)(\varepsilon r)^{-1/\varepsilon}$ and $L = \varepsilon r,$ so extraction is efficient. If A's tenure is infinitesimally small, *h* → ∞, (16) gives $K = \tau^B(\varepsilon r)^{-1/\varepsilon}$ and $L = \left(\frac{1-\tau^A}{\tau^B}\right)^{\varepsilon} \varepsilon r > \varepsilon r,$ so extraction is too fast and more so if A and B shares little of the oil rents.

2.4. Time paths of oil depletion before and after the change of government

Since oil depletion of the incumbent A is excessively fast (*L* > *εr*), initially the path for the oil depletion rate is above the efficient path and the oil price path is below the Hotelling path. If the realised date of the change of government is far enough in the future, the oil depletion rate before the switch can fall below and the oil price path can rise above the efficient path (see appendix 3).

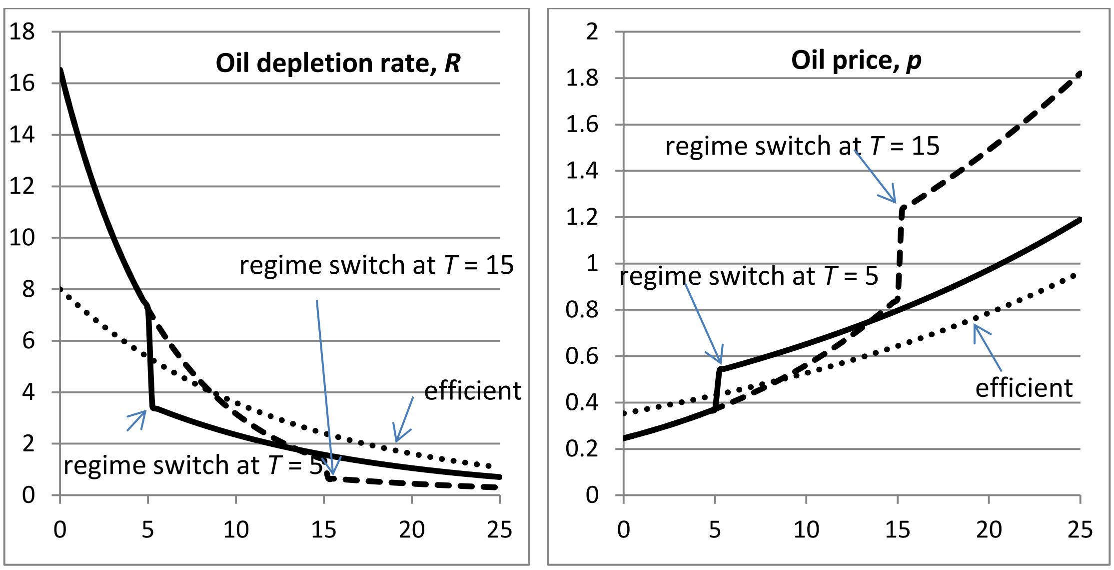
Just before the change in government we have $R(T-) = Le^{-LT}S_0$ and $p(T-) = e^{LT/\varepsilon}(LS_0)^{-1/\varepsilon}.$ Using $S(T) = e^{-LT}S_0,$ we get

(19) $$R(T+) = \varepsilon r e^{-LT}S_0 < R(T-) = Le^{-LT}S_0, \quad p(T+) = e^{LT/\varepsilon}(\varepsilon r S_0)^{-1/\varepsilon} > p(T-) = e^{LT/\varepsilon}(LS_0)^{-1/\varepsilon}.$$

Once A is removed from office, the oil depletion rate jumps down and the price jumps up by a *discrete* amount. From then on depletion and reserves follow Hotelling paths, but they are constrained inefficient as they start out from fewer oil reserves than without political risk. Oil prices rise at the interest rate, but start from a higher level than without political uncertainty as the voracious extraction during A's incumbency has made oil more scarce when B enters office.

To illustrate, Figure 1 reports the results from simulating the model with $\varepsilon = 2$, $r = 0.04$, $S_0 = 100$, $h = 0.1$, $\tau^A = 0$ and $\tau^B = 0.4$. The expected political take-over thus occurs at time 10. The incumbent does not share rents at all, but the rival faction does promise a more cohesive politics.

Figure 1: Oil extraction and price under the risk of being removed from office



Equation (16) gives $K = 2.46$ so $L = 0.165$. The crossing time is 8.5 (from equation (A4) in appendix 3). The reserves to production ratios before and after the regime switch are 6.1 and 12.5, respectively. The dotted lines indicate the efficient outcomes, which prevail if there is no political uncertainty ($h = 0$). The solid lines indicate the inefficient outcomes that result if the realised change of government occurs after 5 units of time. Since $T = 5 < 8.5$, oil depletion rates are always higher and oil prices are always lower than the efficient ones without political uncertainty. The dashed lines correspond to a later change of government with $T = 15 > 8.5$, so the oil depletion and price paths cross the efficient paths before the incumbent leaves office. The simulations confirm that political uncertainty boosts oil depletion rates and depresses oil prices in the period before the change of government. After that, oil depletion jumps down and oil prices jump up and then continue at their less aggressive Hotelling rates.

2.5. Social welfare

Social welfare, *W*, is defined as the sum of the expected welfare of A, i.e., *V*(0), and of B:

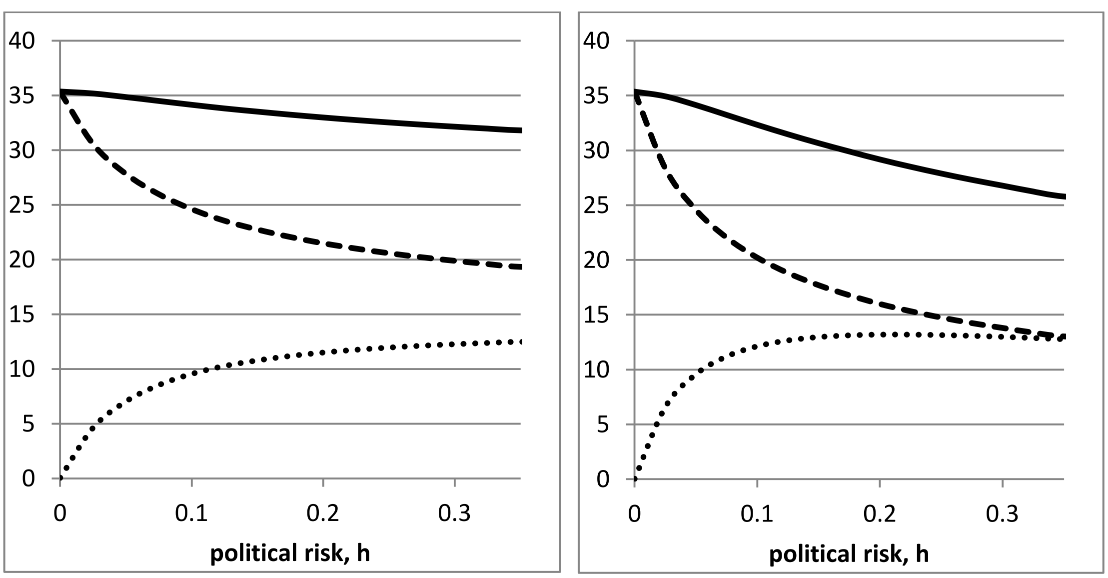
(20)
$$W = \int_0^\infty \left[(LS_0)^{1-1/\varepsilon} \left(\frac{1 - e^{-[r+L(1-1/\varepsilon)]T}}{r + L(1-1/\varepsilon)} \right) + (\varepsilon r)^{-1/\varepsilon} S(T)^{1-1/\varepsilon} e^{-rT} \right] h e^{-hT} dT$$
$$= \left(\frac{h(\varepsilon r)^{-1/\varepsilon} + L^{1-1/\varepsilon}}{r + h + (1-1/\varepsilon)L} \right) S_0^{\;1-1/\varepsilon}.$$

The highest social welfare is attained if there no political risk, $h = 0$, i.e., $W = (\varepsilon r)^{-1/\varepsilon} S_0^{\;1-1/\varepsilon}$.

Figure 2 shows how social welfare (solid lines) and welfare of the incumbent (dashed lines) fall with the degree of political uncertainty. The rival faction's welfare (dotted lines) rises due to the increased chance of gaining office but at a decreasing rate due to the inefficiencies of rapacious resource extraction caused by political uncertainty. Panel (a) shows outcomes for the baseline level of cohesiveness of the future government, i.e., $\tau^B = 0.4,$ and panel (b) for a lower expected cohesiveness, $\tau^B = 0.1.$ Although lower expected cohesiveness induces a small shift in welfare from the incumbent to the rival faction, the main effect is a curbing of the incumbent's and social welfare due to the increased rapacity of resource extraction.

Figure 2: Welfare versus political risk, *h*

(a) Baseline - $\tau^B = 0.4$ **(b) Lower expected cohesiveness -** $\tau^B = 0.1$



Key: Solid lines indicate joint social welfare, dashed lines the incumbent's welfare and dotted lines welfare of the rival faction. B's cohesiveness is 0.4 in panel (a) and only 0.1 in panel (b).

2.6. Exploitation investment and the hold-up problem

Substituting (11) into the incumbent's value function, we get $V(\Omega(I)) = K\Omega(I)^{1-1/\varepsilon}$. The optimal outlay on exploitation investment follow from setting its marginal value to its cost:[8]

(21) $(1-1/\varepsilon)K\Omega(I)^{-1/\varepsilon}\Omega'(I) = q \quad \Rightarrow \quad I = I(h,\tau^A,\tau^B,q), \quad I_{h,}I_{\tau^A}, I_q < 0, I_{\tau^B} > 0.$

Hence, political risk, an obligation to share a bigger fraction of rent, and less expected cohesive payments once out of office depress welfare and make it is less attractive to undertake exploitation investment so that the discovered stock of oil reserves is less. This hold-up problem exacerbates the inefficiencies highlighted in proposition 1 and figures 1 and 2. To the extent that the probability of a change in government increases with the promised cohesiveness by the rival faction, some of the beneficial effects of higher cohesiveness are offset.

3. Ongoing Political Resource Conflict Cycles

We now allow for perennial ongoing switches in political regime. We suppose here that the constitution dictates the same cohesiveness for both factions, $\tau^A = \tau^B \equiv \tau$, and that the probability of being removed from office, *h*, is the same whatever faction is in government. Since we focus at symmetric (asymptotic) Nash equilibrium outcomes, there is no need to distinguish the value functions for the two factions separately. We thus denote the in-office value function by $V(S)$ and the out-of-office value function by $V^*(S)$. In contrast to section 2, we introduce a partisan in-office bias, $\beta \geq 1$, to reflect that the incumbent enjoys utility more in office rather in opposition (cf. Aguiar and Amador, 2011). The HJB equation for when in office is thus

(22) $\underset{R}{\text{Max}}\left[\beta(1-\tau)p(R)R - V'(S)R\right] - h\left[V(S) - V^*(S)\right] = rV(S).$

The value of being out of office is the present value of expected cohesiveness payments received when out of office plus the expected net rents upon gaining office, so that the HJB equation is

(23) $rV^*(S) = \tau p(R)R - V^{*'}(S)R + h\left[V(S) - V^*(S)\right].$

From the HJB equation (22) the marginal revenue corrected for in-office bias must equal the shadow value of oil, $\beta(1-1/\varepsilon)(1-\tau)p(R) = V'(S).$ We obtain the following proposition.

[8] The signs of the partial derivatives in the second part of (21) follow from total differentiation of the first part: $q\left[[\Omega'(I)/\varepsilon\Omega(I)] - \Omega''(I)/\Omega'(I)\right]dI = -dq + (q/K)(K_h dh + K_{\tau^A} d\tau^A + K_{\tau^B} d\tau^B).$

Proposition 2: *With perennial ongoing political cycles, resource depletion is rapacious and faster than predicted by the competitive Hotelling rule ($L > \varepsilon r$), especially if the political system is less cohesive (low τ), the partisan in-office bias (β) is large, and there are frequent changes of government (high h). Political instability curbs value to the go of the incumbent.*

Proof: See appendix 2.

Partisan bias now makes resource extraction in this situation with two-sided regime switches more voracious just like political uncertainty and less cohesive constitutions.

4. Dynamic resource wars: strategic, two-way regime switches

We extend the two-sided regime switch model of perennial political turnover of section 3 to allow the hazard rates to be endogenous. The hazard rates depend on fighting and are strategically determined. This more general framework allows us to analyse the dynamic interactions between resource extraction and wars and to understand the political determinants of resource extraction and political turnover. We analyse the two-way interaction between resource extraction and conflict when there is uncertainty about who controls natural resources. By diverting labour from productive activities, the incumbent engages in a costly fight to increase their grip on office and the proceeds of oil whilst the incumbent engages in a fight to improve the chances of removing the incumbent from office and gain control of oil. We thus offer an infinite-horizon game-theoretic analysis of ongoing resource wars with repeated switches of government regime.[9]

4.1. The model

We denote by an asterisk outcomes for the factions if they are out of office. If A is the incumbent, factions A and B fight f^A and f^{B*} units of time, respectively and thus have $N - f^A$ and $N - f^{B*}$ units of time left for work with N the exogenous labor supply of each faction. If B is the incumbent, factions A and B fight, respectively, f^{A*} and f^B units of time and work $N - f^{A*}$ and $N - f^B$ units of time. The opportunity cost of fighting is the exogenous wage W. The hazard rates of faction A being replaced by B and of faction B by A depend on relative fighting efforts and are given by:

$$(24) \qquad h^A = \frac{2H(f^{B*})^\phi}{(f^A)^\phi + (f^{B*})^\phi}, \quad h^B = \frac{2H(f^{A*})^\phi}{(f^{A*})^\phi + (f^B)^\phi}, \qquad H > 0, \quad 0 < \phi \le 1.$$

[9] This contrasts with the two-period analysis of van der Ploeg and Rohner (2012).

Equations (24) imply that by fighting more intensively each faction improves chances of entering office and gaining control of oil reserves. Further, a rebel faction that does not fight, never gains office. If both the incumbent and the rebel faction fight with the same intensity, the hazard of being removed from office is *H*. If the incumbent does not make any effort to fend off rebels, its hazard of being removed from office is twice as high, 2*H*. By fighting much more than the rebel faction, it could in principle increase its grip on office by curbing the hazard of being removed from office. Our hazard rates functions are akin to the contest success functions used in the static conflict literature (e.g., Tullock, 1967; Hirshleifer, 1991; Skaperdas, 1996; Konrad, 2009), which finds that conflict increases in the stakes and decisiveness of conflict technology.[10]

Four key parameters characterise outcomes. The first one is *H* and stands for how fast elections take place or for *core political instability*. The second parameter is the *cohesiveness* of the political system, $0 < \tau \leq 0.5$, and indicates the share of oil rents the incumbent gives to the rebel faction (as in sections 2 and 3). The third parameter is the *partisan in-office bias*, $\beta \geq 1$, and indicates the extra weight given by the incumbent to net rents when in office (as in section 3). The fourth parameter is ϕ and indicates *fighting technology*, which is subject to non-increasing returns to scale ($\phi \leq 1$). A high ϕ implies that the effect of incumbent fighting on the chance of being removed from office and for rebels fighting on their chance of gaining office is high.

The incumbent fights to improve its chance of staying in office and chooses the optimal rate of oil extraction. The contender fights to try to get into office and control oil. We use (24) to write A's HJB equations for the non-cooperative subgame-perfect Nash equilibrium outcome as follows:

$$\text{(25)} \qquad \underset{f^A, R^A}{\text{Max}} \left\{ \beta(1-\tau) p(R^A) R^A - V_S^A(S) R^A + W(N - f^A) - h^A \left[V^A(S) - V^{A*}(S) \right] \right\} = rV^A(S),$$

$$\text{(26)} \qquad \underset{f^{A*}}{\text{Max}} \left\{ \tau p(R^B) R^B - V_S^{A*}(S) R^B + W(N - f^{A*}) + h^B \left[V^A(S) - V^{A*}(S) \right] \right\} = rV^{A*}(S),$$

where h^A and h^B depend on relative fighting efforts and are given by (24). There are two similar HJB equations for B in $V^B(S)$ and $V^{B*}(S)$. Equation (25) states that the incumbent's maximum oil rents (net of any share of oil revenue transferred to the rival faction and net of the shadow cost of oil) *plus* income from productive activities *minus* the expected loss in value terms of losing office must equal the return from investing oil proceeds at the market rate of interest. Equation (26) states

[10] This literature also finds that less productive groups fight harder and have a higher winning chance than richer groups. Our model also yields these results if we let the wage differ for the two factions.

that the contender's cohesiveness transfers *plus* wage income *plus* the expected gain of entering office must equal the market rate of return. Asymptotically, the effect of which faction started in office withers away and the in- and out-office value functions for the two factions converge. We will use this to make our analysis simpler and thus concentrate on the asymptotic subgame-perfect Nash equilibrium outcome.

4.2. Non-cooperative outcomes for fighting intensities and resource extraction

The Nash non-cooperative outcome supposes that, if faction A is in office, it takes as given rebel fighting efforts, f^{B*}, when choosing its optimal fighting efforts, f^A, and oil depletion rate, R^A. If A is the rebel faction, it takes fighting efforts of the incumbent, f^B, as given when deciding on its fighting efforts, f^{A*}. Faction A's marginal expected gain from, respectively, fighting in and out of office is set to its opportunity cost of fighting (the wage):

(27) $$\left(\frac{2\phi H(f^A)^{\phi-1}(f^{B*})^{\phi}}{\left[(f^A)^{\phi}+(f^{B*})^{\phi}\right]^2}\right)\left[V^A(S)-V^{A*}(S)\right]=\left(\frac{2\phi H(f^{A*})^{\phi-1}(f^B)^{\phi}}{\left[(f^{A*})^{\phi}+(f^B)^{\phi}\right]^2}\right)\left[V^A(S)-V^{A*}(S)\right]=W$$

and similarly for faction B.[11] Equations (27) yield two reaction functions for when faction A is in and out of office indicating that A will fight more if B fights more (both if A is in and out of office). The intersection with the complementary reaction functions for faction B gives the non-cooperative symmetric Markov-perfect Nash equilibrium. Since the cohesiveness parameter, fighting technology and the wage are the same for both factions and the hazard rates are given by symmetric contest functions, the non-cooperative Nash equilibrium outcome is symmetric. We thus get from (27) and its counterpart for B the following symmetric Nash equilibrium fighting intensities:

(28) $$f^A = f^{A*} = f^B = f^{B*} = \frac{\phi H}{2W}\left[V(S)-V^*(S)\right].$$

We see from (28) that fighting increases if the expected gain from staying or getting into office is high relative to the opportunity cost of fighting (W). Further, fighting is more intense if fighting technology has less decreasing returns to scale (higher ϕ) and it is easier to remove the incumbent

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[11] The second-order optimality condition for f^A requires that $d\left((f^A)^{\phi-1}\left[(f^A)^{\phi}+(f^{B*})^{\phi}\right]^{-2}\right)/df^A =$ $\left[-(1+\phi)(f^A)^{2\phi-2}+(\phi-1)(f^A)^{\phi-2}(f^{B*})^{\phi}\right]\left[(f^A)^{\phi}+(f^{B*})^{\phi}\right]^{-3}<0,$ and similarly for the other three second-order conditions. At the symmetric equilibrium (see (28) below), the right-hand side boils down to $-f^{-2-\phi}/4<0$ so the second-order optimality conditions indeed hold.

from office (higher H). The result that (asymptotically) fighting efforts are the same whether one is in or out of office is a result of the specific functional form of the hazard rates (24). Note that there is no direct effect of cohesiveness of partisan bias on fighting efforts, only via the value functions. Substituting (28) into (24), we establish that in equilibrium $h^A = h^B = H$ and thus the HJB equations for when in and out of office become, respectively:

(25′) $$\underset{R^A}{\text{Max}} \left\{ \beta(1-\tau)p(R)R - V'(S)R + WN - (1+0.5\phi)H\left[V(S) - V^*(S)\right] \right\} = rV(S),$$

(26′) $$\tau p(R)R - V^{*'}(S)R + WN + (1-0.5\phi)H\left[V(S) - V^*(S)\right] = rV^*(S).$$

The incumbent sets marginal revenue (net of cohesiveness payments) to marginal social cost:

(29) $$\beta(1-\tau)(1-1/\varepsilon)p(R) = V'(S).$$

Equation (29) implies that the oil price is low and the rate of oil depletion high if oil is abundant (high S and low $V'(S)$), cohesiveness of the political system is weak (low τ), and the partisan bias is big (large β). To solve the simultaneous HJB equations (25′) and (26′) together with (29), we conjecture that the asymptotic value functions are given by $V^A(S) = V^B(S) = KS^{1-1/\varepsilon} + WN/r$ and $V^{A*}(S) = V^{B*}(S) = K^* S^{1-1/\varepsilon} + WN/r$ with K and K^* constants to be determined. Using these conjectured value functions, we find from (29) the optimal oil price and oil depletion rates:

(30) $$p = \frac{K}{\beta(1-\tau)} S^{-1/\varepsilon}, \quad R = LS, \qquad L \equiv \left[\beta(1-\tau)\right]^{\varepsilon} K^{-\varepsilon}.$$

Substituting (30) into (25′) and (26′) and equating coefficients on $S^{1-1/\varepsilon}$, we get:

(31) $$\frac{1}{\varepsilon}\left[\beta(1-\tau)\right]^{\varepsilon} K^{1-\varepsilon} - (1+0.5\phi)H(K-K^*) = rK,$$

(32) $$\tau\left[\beta(1-\tau)\right]^{\varepsilon-1} K^{1-\varepsilon} - (1-1/\varepsilon)\left[\beta(1-\tau)\right]^{\varepsilon} K^{-\varepsilon} K^* + (1-0.5\phi)H(K-K^*) = rK^*.$$

These two nonlinear algebraic equations can be solved for K and K^*, which can then be substituted into (32) to get oil prices and depletion rates and (from (28)) fighting efforts:

(33) $$f = f^* = \frac{\phi H}{2W}(K-K^*)S^{1-1/\varepsilon}.$$

4.3. Characterizing the non-cooperative Nash equilibrium

To characterise the non-cooperative Nash outcomes, we first consider three special cases.

First, if the political system is perfectly cohesive in the sense that all resource rents are shared equally between parties independent of whether they are in office or not ($\tau = 0.5$) and there is no partisan in-office bias (β = 1), it is easy to establish from (31)-(32) that the solution is $K = K^{*} = 0.5(\varepsilon r)^{-1/\varepsilon}, L = \varepsilon r$ and thus $R = \varepsilon r S$ and from (33) $f = 0$, regardless of the fighting effectiveness ϕ. Hence, a perfectly cohesive political system without partisan bias is efficient and ensures that there is no armed conflict.

Second, if it is not possible to remove factions from political office, i.e., the hazard rate H is zero, there is no point in fighting, (31) solves for $K = \beta(1-\tau)(\varepsilon r)^{-1/\varepsilon}$ (whilst K^{*} is irrelevant) and (30) gives $p = (\varepsilon r S)^{-1/\varepsilon}$ and $R = \varepsilon r S$. Hence, if factions cannot be removed from office, the outcome is also efficient irrespective of the degree of political cohesion, τ, or the partisan in-office bias, β.

Third, if there is a partisan in-office bias (β > 1), zero cohesiveness ($\tau = 0$), and fighting effectiveness is quadratic in effort (ϕ = 2), one can establish from equations (31) and (32) that $K = \beta\left[\varepsilon(r+2H)\right]^{-1/\varepsilon}, K^{*} = 0, L = \varepsilon(r+2H) < \varepsilon r$ and $f = f^{*} = \beta\left[\varepsilon(r+2H)\right]^{-1/\varepsilon} HS^{1-1/\varepsilon} / W$. We thus establish that for this case that more core political instability (higher H) leads to a more voracious speed of resource extraction. It can also be shown that this increases fighting intensities (higher f). Interestingly, a bigger partisan in-office bias (higher β) does not affect the speed of resource extraction for this case. It does, however, boost fighting and conflict. The fighting induces efficiency losses over and above the losses from rapacious resource depletion.

The following proposition generalises these insights to allow for dynamic resource wars.

Proposition 3: *Dynamic resource wars are more intense if oil reserves are high and workers are paid poorly. Depletion of oil reserves is less rapid if a greater share of oil revenue is shared with rebels (bigger τ). This is also the case if government stability is higher (lower H). and fighting technology displays decreasing returns (lower ϕ) in which case welfare for the incumbent rises. A partisan in-office bias (β > 1) leads to more rapacious oil depletion, especially if the political system is more cohesive and more of oil rents have to be shared.*

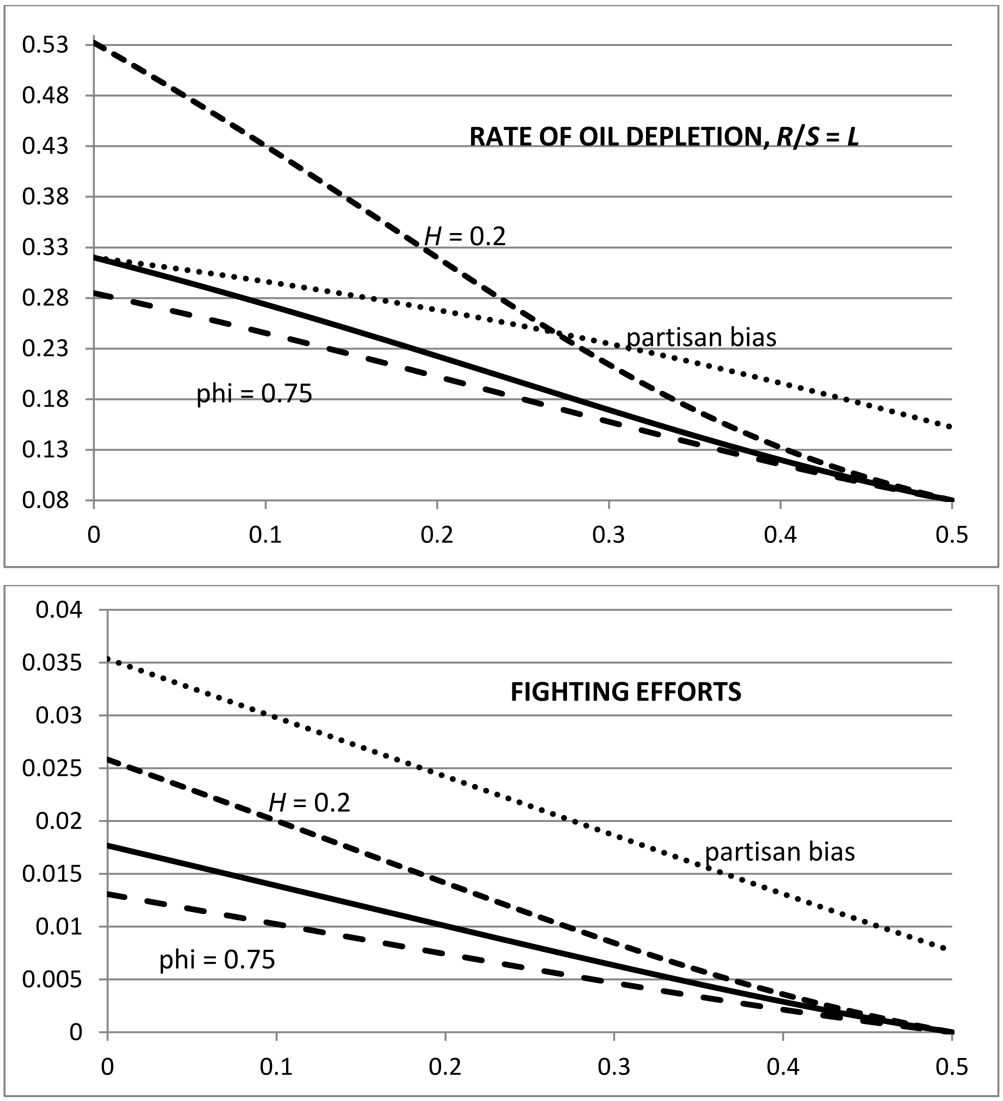
Proof: See appendix 2.

4.4. Numerical illustrations

Figure 3 plots the effects of the cohesiveness share given to rebels, τ, on oil depletion rates and fighting intensities and figure 4 plots the values to go with baseline parameters set to ε = 2, r = 0.04,

S_0 = 100, H = 0.1, N = 0.2 and W = 8. In line with proposition 3 we see that more cohesiveness leads to less rapacious oil depletion. It also leads to less armed conflict. Figure 4 indicates that the more oil rents are shared, i.e., the more cohesive the political system, the higher the value to the rebels and the higher joint value to go, but the incumbent's value to go first decreases slightly and then increases slightly with cohesiveness.

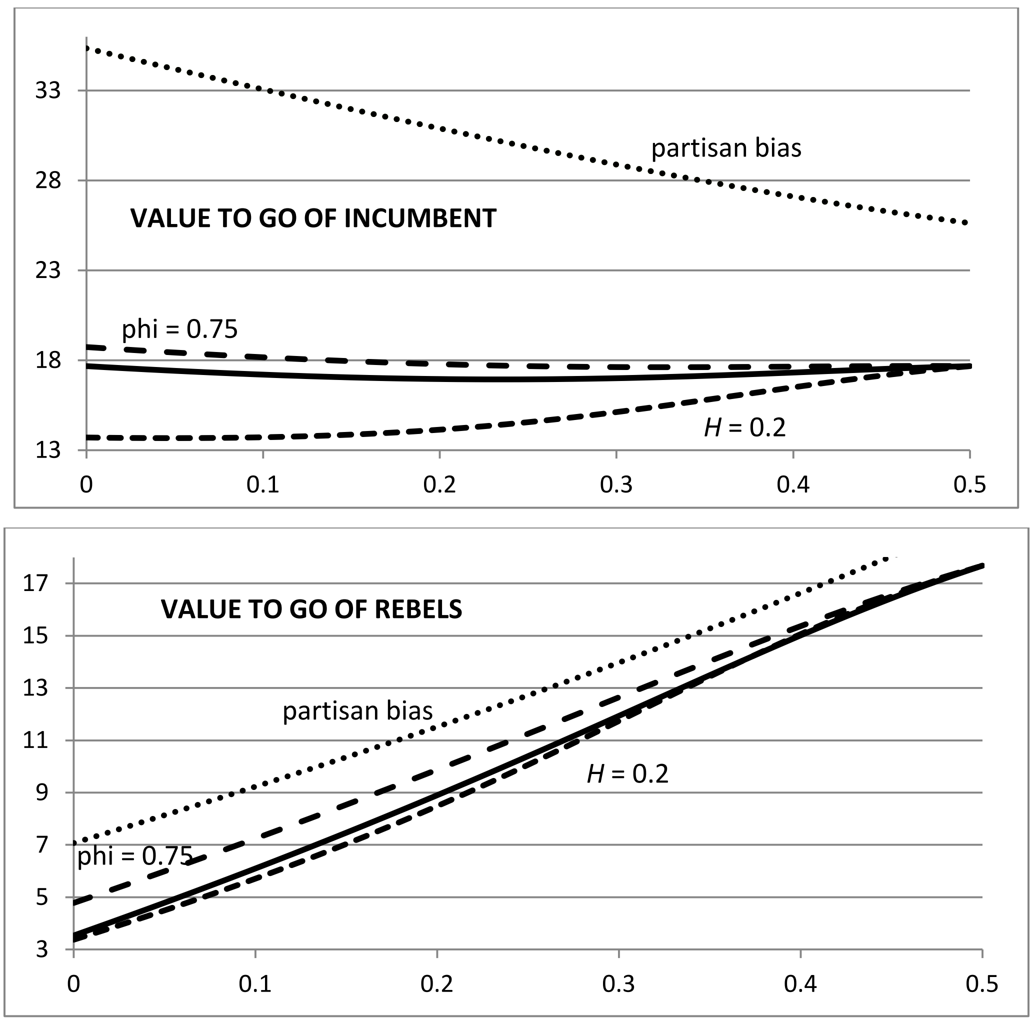
Figure 3: Oil depletion rates and fighting intensities ($f = f^*$) versus cohesiveness rate (τ)

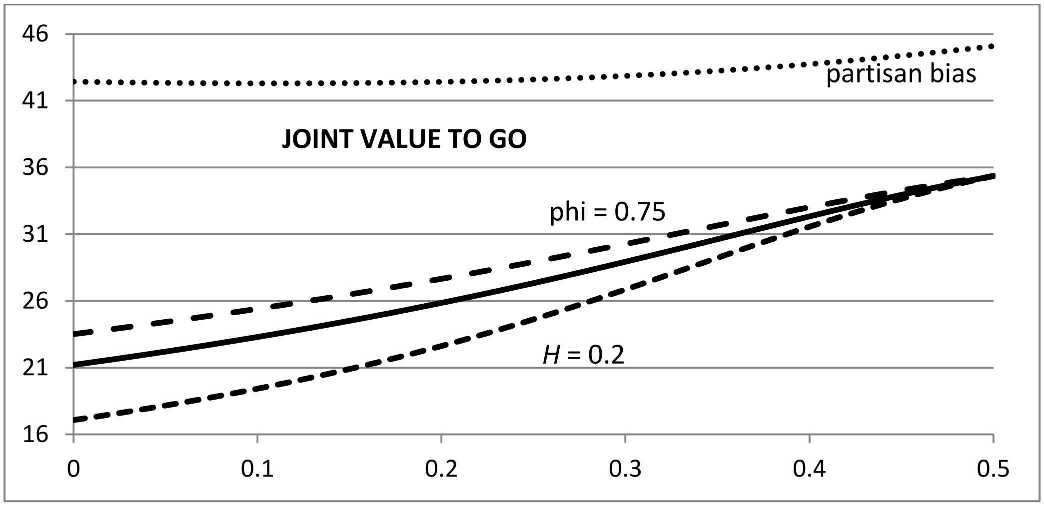


The short-dashed lines in figure 3 show that more political instability (H = 0.2 > 0.1) induces more rapacious oil depletion in line with proposition 3 and more intensive fighting, especially if the political system is less cohesive. Effectively, if the possibility of being removed from office is more imminent, the ruling faction is fearful of losing control of the oil stake and the rebels find it more attractive to fight. Figure 4 shows that the inefficiencies causes by conflict and rapacious depletion resulting from more political instability depress value to go for the incumbent and the rebel factions, especially if the political system is not very cohesive. Hence, oil-rich countries with few elections and where the incumbent is hard remove from office have less conflict than oil-rich countries with regular, hotly contested elections.

The long-dashed lines in figure 3 show that decreasing returns in fighting technology ($\phi = 0.75 < 1$) curb rapacious depletion in line with proposition 3 and leads to less intense resource wars, especially if the political system is less cohesive. As a result, figure 4 indicates that payoffs to both the ruling and rebel factions increase, more so if the political system is less cohesive. Worse fighting technology can thus make factions better off in countries that are rich in oil.

Figure 4: Values to go versus political cohesiveness (τ)





The dotted line in the top panel of figure 3 confirm proposition 3 in that a partisan in-office bias (β = 2 > 1) induces more rapacious resource depletion especially for more cohesive political systems. Another way of putting this is that the adverse effect of a partisan in-office bias on the rate of resource depletion can be offset with a more cohesive political system. The dotted line in the bottom panel indicates that a partisan in-office bias induces for any given degree of cohesiveness more conflict as incumbents want to cling to office. Figure 4 indicates that a partisan in-office bias increases value to go for rebels. The increase in the incumbent's value to go tapers off strongly as the cohesiveness of the political system is increased. This is why joint value to go rises only slightly as the degree of cohesiveness increases.

Finally, table 1 confirms that conflict is more intense, despite the speed of depleting oil reserves being unaffected, if the stake (oil reserves, S) is high and the opportunity cost of fighting (the wage, W) is low. A higher oil stake increases payoff to both ruling and the rebel factions. A lower wage leaves payoffs from oil unaffected. Fighting is less intense if rebels are more patient (lower r of 0.02 instead of 0.04) in which case oil depletion is less rapid and payoffs to both the ruling and the rebel faction (as does human capital) increase.

Table 1: Sensitivity of speed of oil extraction and fighting efforts

	V	V^*	$V + V^*$	$L = R/S$	f
Benchmark: $\tau = 0.25$, $\beta = \phi = 1$, $H = 0.1$	16.94	10.40	27.34	0.196	0.082
Double the initial oil stock: $S(0) = 200$	23.96	14.71	38.67	0.196	0.116
Half the wage: $W = 4$	16.94	10.40	27.34	0.196	0.163
Halving the interest rate: $r = 0.02$	20.59	14.23	34.82	0.133	0.079

4.5. Effects on oil exploitation investment and initial reserves

Analogously to (21), we find that $I = I\left(K(\beta,\tau,\phi,H)\right), \quad I_\phi, I_H < 0,$ so more political stability and decreasing returns to fighting technology leads to more oil exploitation investment and higher initial oil reserves. This boosts welfare further than indicated in figure 4. Similarly, a partisan in-office bias increases the value to go for the incumbent and thus boosts oil exploitation and initial reserves, and more so if the political system is not very cohesive. Cohesiveness itself has a non-monotonic effect on value to go for the incumbent as shown in figure 4 and thus has a non-monotonic effect on oil exploitation and initial reserves.

5. Conclusion

Dynamic resource wars are a prevalent feature both of history and the present day. To understand such wars it is vital to understand the two-way link between natural resource extraction and conflict. Using a dynamic model with two-way political regime switches, resource extraction and fighting, we show that fighting is more intense and oil extraction more rapacious if the political system is less cohesive in the sense that the ruling faction gives a smaller share of oil revenue to rebels.[12] Conflict is also more intense if oil reserves are high, workers and soldiers are paid badly, factions are impatient, and fighting technology is more effective. And resource wars are more intense if there is not much change-over of governments, although the depletion of oil reserves is then less rapid. With the ruling faction being challenged by rebels over the control of natural resources, extraction becomes more voracious, especially if fighting technology is more effective. A partisan in-office bias induces more rapacious oil depletion, especially if the political system is more cohesive. A more cohesive political system can thus offset the inefficiencies in the rate of oil depletion caused by a partisan in-office bias. This is not the case for conflict, since fighting is increased by a partisan in-office bias regardless of the cohesiveness of the political system.

Our dynamic model of resource wars is based on a political economy model where political factions alternate in office and control of resources, but the hazards of being removed from office are exogenous. Political uncertainty leads to regime switch uncertainty which induces rapacious depletion of natural resources, especially if the political system is less cohesive and less of oil rents are shared, the partisan in-office bias is large and governments are frequently removed from office.

[12] This contrasts with the central case of inelastic oil demand discussed in Acemoglu et al. (2012), where oil extraction is too slow and incentives for war are mitigated.

Both our model of resource wars and our political model of two-way regime switches build on the theory of confiscation risk facing a resource-owning monopolist. To get tractable analytical results, we have assumed iso-elastic demand and zero variable oil extraction costs. Extraction rates are then efficient and oil prices follow Hotelling paths even if confiscation has taken place and oil revenue is taxed. The risk of confiscation, not confiscation itself, leads to faster depletion of reserves and oil prices rising more rapidly than the Hotelling paths.[13] These inefficiencies are exacerbated by a hold-up problem, since the risk of creaming off oil profits depresses outlays on exploitation investment. This can be corrected for with an appropriate subsidy on exploitation investment, which rises with confiscation risk.

Various extensions are of interest. If the probability of confiscation decreases as untapped oil reserves fall, the benevolent incumbent will pump oil even more vigorously to make it less likely to be booted out by a populist contender. If the demand elasticity increases (decreases) as oil demand falls, the monopolistic rate of oil depletion will be too slow (rapid)[14] thus reducing (increasing) incentives to fight about the control of resources. If oil depletion becomes more expensive as less accessible fields are explored, the speed of oil depletion will be more conservative and thus incentives for war will be higher. More general contest functions may allow for regimes of suppressed conflict (Besley and Persson, 2011a). If resource production is capital (labour) intensive, higher (lower) resource prices boost the return on capital and lower the wage and thus intensify war and conflict (Dal Bo and Dal Bo, 2011; Dube and Vargas, 2013). It is of interest to examine how this influences the rate of natural resource extraction in general equilibrium. It is also important to allow for the potential effect of conflict on exchange rates and the potential erosion of the value of resource exports. Finally, cohesive societies build up states in the face of military conflict to finance armies whilst less cohesive societies do not and thus drop out of conflict (e.g., Gennaioli and Voth, 2015) and it is of interest to study how the building of state capacity is affected by the presence of a large stock of natural resources.

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[13] Our model of confiscation risk is akin to the effects of an uncertain time at which an oil cartel is broken up and whether this leads the cartel to overproduce (Benchekroun et al., 2006), the interplay between political risk and foreign investment (Cherian and Perotti, 2001), and the role of wealth distribution and wealth accumulation on regime switches between bad and good property rights (e.g., Tornell, 1997; Leonard and Long, 2011).

[14] Linear demand has increasing price elasticity and more conservative depletion (Stiglitz, 1976). This also occurs with semi-loglinear demand. But power utility with subsistence need for oil, $R = \bar{R} + p^{-\hat{\varepsilon}}$ with $\bar{R} > 0$ and $\varepsilon = \hat{\varepsilon} / (1 + \bar{R}p^{\hat{\varepsilon}}) < \varepsilon$ has a falling price elasticity and too rapid oil depletion.

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Appendix 1: Derivation of HJB equations with hazard of a regime switch

Since the probability of a regime shift in an infinitesimally small time period Δt is $h\Delta t$, the Principle of Optimality from the perspective of time zero can be written as follows:

(A1) $$e^{-rt}V\left(S(t)\right) = \underset{R^B}{\text{Max}}\left[\int_t^{t+\Delta t} e^{-rs}\, p\left(R(s)\right)R(s)ds + (1-h\Delta t)e^{-r(t+\Delta t)}V\left(S(t+\Delta t)\right) + h\Delta t e^{-r(t+\Delta t)}V^A\left(S(t+\Delta t)\right)\right].$$

Multiplying both sides by e^{rt}, rearranging and dividing by Δt, we rewrite (A1) as:

(A2) $$\underset{R^B}{\text{Max}}\left[\frac{\int_t^{t+\Delta t} e^{-r(s-t)}\, p\left(R(s)\right)R(s)ds}{\Delta t} - he^{-r\Delta t}V\left(S(t+\Delta t)\right) + he^{-r\Delta t}V^A\left(S(t+\Delta t)\right) \frac{\left(e^{-r\Delta t}-1\right)V\left(S(t+\Delta t)\right)}{\Delta t} + \frac{V\left(S(t+\Delta t)\right) - V\left(S(t)\right)}{\Delta t}\right] = 0.$$

Evaluating the integral in (A2) for infinitesimally small Δt and taking the limit as $\Delta t \to 0$ whilst using l'Hôpital's Rule for $\lim_{\Delta t \to 0} \frac{\exp(-r\Delta t)-1}{\Delta t} = -r,$ and taking terms that do not depend on $R(t)$ outside the square brackets, we get:

(A3) $$\underset{R^B}{\text{Max}}\left[p\left(R(t)\right)R(t) - \dot{V}\left(S(t)\right)\right] - hV\left(S(t)\right) + hV^A\left(S(t)\right) - rV\left(S(t)\right) = 0.$$

Substituting $\dot{V} = V'(S)\dot{S}$ and using (2), rearranging and dropping the time index, we get the HJB equation (13).

A similar procedure is used to derive the HJB equations (22) and (23) for the model of perennial political cycles put forward in section 3 and the HJB equations (25) and (26) for the model of dynamic resource wars discussed in section 4.

Appendix 2: Proofs

Proposition 1: From (16) $K=(1-\tau^A)(\varepsilon r)^{-1/\varepsilon}$ and $L=\varepsilon r$ if h = 0 and $K=\tau^B(\varepsilon r)^{-1/\varepsilon}<(\varepsilon r)^{-1/\varepsilon}$ and $L=\left(\frac{1-\tau^A}{\tau^B}\right)^{\varepsilon}\varepsilon r\geq\varepsilon r$ if $h\to\infty$. Totally differentiating (16) gives

(16′)
$$dK=\frac{-(L-\varepsilon r)(K/\varepsilon h)dh-(\tau^A/K)^{\varepsilon-1}d\tau^A+h(\varepsilon r)^{-1/\varepsilon}d\tau^B}{r+h+(1-1/\varepsilon)L}\quad\Rightarrow$$
$$K=K(h,\tau^A,\tau^A),\quad K_h<0,K_{\tau^A}<0,K_{\tau^B}>0.$$

We can show $L=L(h,\tau^A,\tau^B)$ with $L_h>0,L_{\tau^A}<0$ and $L_{\tau^B}<0.$ The ratio of oil reserves to production, S/R, before the political take-over, $1/L$, is smaller than afterwards, $1/\varepsilon r$. □

Proposition 2: Substituting this and the conjectured value functions, $V(S)=KS^{1-1/\varepsilon}$ and $V^*(S)=K^*S^{1-1/\varepsilon}$, and oil demand $R=LS$ with $L\equiv[\beta(1-\tau)]^{\varepsilon}K^{-\varepsilon}$ into (22) and (23) and equating coefficients on $S^{1-1/\varepsilon}$ gives two equations that can be solved for K or L and K^*:

(22′) $$\frac{1}{\varepsilon}[\beta(1-\tau)]^{\varepsilon}K^{1-\varepsilon}-H(K-K^*)=rK,$$

(23′) $$\tau[\beta(1-\tau)]^{\varepsilon-1}K^{1-\varepsilon}-(1-1/\varepsilon)[\beta(1-\tau)]^{\varepsilon}K^{-\varepsilon}K^*+H(K-K^*)=rK^*.$$

Using this we get $K^*=\left[\frac{\varepsilon\left(\frac{\tau}{\beta(1-\tau)}\right)L+\varepsilon H}{\varepsilon(r+H)+(\varepsilon-1)L}\right]K.$ Putting this in (22′) gives

(A4) $$(\varepsilon-1)L^2+\Xi L-\varepsilon^2 r(r+2H)=0,\quad \Xi\equiv\varepsilon[2(r+H)-\varepsilon r]-\varepsilon^2 H\left(\frac{\beta(1-\tau)-\tau}{\beta(1-\tau)}\right).$$

Picking the positive solution to equation (A4) gives the equilibrium speed of oil extraction,

(A5) $$\frac{R}{S}=L=\frac{\sqrt{\Xi^2+4(\varepsilon-1)\varepsilon^2 r(r+2H)}-\Xi}{2(\varepsilon-1)}>0,$$

upon which and K, K^* and values to go follow. Total differentiation of (A4) yields:

(A4′) $$[2(\varepsilon-1)L+\Xi]dL = 2\varepsilon^2 r dH + \varepsilon^2 H\left(\frac{\tau}{\beta^2(1-\tau)}\right)L d\beta - \varepsilon^2 H\left(\frac{(1+\beta)(\beta-1)\tau+\beta}{\beta(1-\tau)}\right)L d\tau.$$

Since $2(\varepsilon-1)L+\Xi>0,$ we deduce $\partial L/\partial\beta>0, \partial L/\partial\tau<0$ and $\partial L/\partial H>0.$ The effect of β on L is zero if $\tau = 0$ and increases in τ. It follows from (A4′) that $\partial K/\partial H<0.$ The effect of τ on K is non-monotonous. □

Proposition 3: Using $R/S = [\beta(1-\tau)]^{\varepsilon} K^{-\varepsilon} \equiv L,$ we use (32) to obtain

(32′) $$K^* = \left[\frac{\varepsilon\left(\frac{\tau}{\beta(1-\tau)}\right)L + \varepsilon(1-0.5\phi)H}{\varepsilon[r+(1-0.5\phi)H]+(\varepsilon-1)L}\right]K.$$

We can use (32′) to rewrite (31) as a quadratic equation in L:

(31′) $$(\varepsilon-1)L^2 + \Xi L - \varepsilon^2 r(r+2H) = 0, \quad \Xi \equiv \varepsilon[2(r+H)-\varepsilon r] - \varepsilon^2(1+0.5\phi)H\left(\frac{\beta(1-\tau)-\tau}{\beta(1-\tau)}\right).$$

Picking the positive solution to equation (31′) gives the equilibrium speed of oil extraction,

(A6) $$\frac{R}{S} = L = \frac{\sqrt{\Xi^2 + 4(\varepsilon-1)\varepsilon^2 r(r+2H)} - \Xi}{2(\varepsilon-1)} > 0,$$

and thus K. Subsequently, one gets K^* from (32′), fighting efforts from (33) and values to go for each of the factions. Total differentiation of (31′) yields:

(A7) $$[2(\varepsilon-1)L+\Xi]dL = \varepsilon^2\left[2r + 0.5\phi\left(\frac{\beta(1-\tau)-\tau}{\beta(1-\tau)}\right)L\right]dH + 0.5H\varepsilon^2\left(\frac{\beta(1-\tau)-\tau}{\beta(1-\tau)}\right)d\phi$$
$$+\varepsilon^2(1+0.5\phi)H\left(\frac{\tau}{\beta^2(1-\tau)}\right)L d\beta - \varepsilon^2(1+0.5\phi)H\left(\frac{(1+\beta)(\beta-1)\tau+\beta}{\beta(1-\tau)}\right)L d\tau.$$

At the solution to the quadratic equation (31′) the derivative of the quadratic slopes upwards, so that $2(\varepsilon-1)L+\Xi>0$ and thus from (A7) we deduce $\partial L/\partial\beta>0, \partial L/\partial\tau<0, \partial L/\partial\phi>0$ and $\partial L/\partial H>0.$ The effect of β on L is zero if $\tau = 0$ and increases in τ. It follows from the definition of L that $\partial K/\partial\phi<0$ and $\partial K/\partial H<0.$ The effect of τ on K is non-monotonous. □

Appendix 3: Time at which incumbent's oil depletion rate falls below efficient rate

The oil depletion rate before the switch of government is below the efficient rate for all $t > T^*$, where T^* follows from $Le^{-LT^*} = \varepsilon r e^{-\varepsilon r T^*}$:

(A8) $$T^* = \frac{\ln\left(L(h,\tau^A,\tau^A)/\varepsilon r\right)}{L(h,\tau^A,\tau^A)-\varepsilon r} \equiv T^*(h,\tau^A,\tau^A) > 0.$$

Consider $\partial T^* / \partial L = [L - \varepsilon r - L\ln(L/\varepsilon r)]/[L(L-\varepsilon r)^2]$. The denominator is positive and the derivative of the numerator is $-\ln(L/\varepsilon r) < 0$. Hence, as the numerator approaches zero as L approaches εr, we have $\partial T^* / \partial L < 0$. Hence, $T_h^* < 0, T_{\tau^A}^* < 0$ and $T_{\tau^B}^* > 0.$ A higher probability of being removed from office thus brings forward the date (provided A is still in office) that the oil depletion rate falls below efficient extraction rate and that the oil price moves above the efficient path of oil prices.