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Water scarcity and conflict - a reciprocal problem?

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Abstract

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Keywords: Conflict · Natural Resources · Water Scarcity

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1 Introduction

A usual argument in the climate change discussions, is that a more severe climate change leads to more intense conflicts as several resources such as land and water might become scarcer.[1] Another correlation of resource use and (possible) conflict with the same direction but another causality was derived by Long (1975) and brought to interconnection with the climate change problem by Sinn (2008). While the formers analyses are intended to represent fossil fuels we consider it useful for water aswell. Given the the strong emphasis on the water scarcity in United Nations Development Programme (2009) exhaustibility, or at least stock diminishment, of ground water are seems to be a major concern. Our analysis shows that by endogenizing expropriation threats an effect in the opposite might emerge. Consequently, it is possible that a *tradeoff* between conserving strategies and peacekeeping exist.

The paper proceeds in the following manner; section 2 derives the benchmark case of a certain sole owner, which follows the Hotelling (1931) rule. Section 3 presents a short overview on the model structure and the parameters of the model. Its subsections provide the solutions of the model. In particular they demonstrate the differences between open loop and closed loop like strategies in our framework. Section 4 discusses the resulting policy implications; we conclude in section 5.

2 The sole owner benchmark

The first step is to calculate a benchmark setting of a certain sole owner, to get some reference point for efficiency concerns. As in the later model discounting is neglected, the model abstract from extraction costs and time is considered to consist of two periods $t = 1, 2$. A resource owner therefore faces the problem to maximize the expression:

$$\Pi = p_1(r_1)r_1 + p_2(r_2)r_2 \tag{1}$$

with respect to the extraction rates r_t, such that the resource constraint $S_1 = r_1 + r_2$, where S_1 denotes the water stock at the beginning of $t = 1$, is fulfilled. Straightforward calculation leads to the first order conditions:

$$\lambda = p_1' r_1 + p_1 = p_2' r_2 + p_2, \tag{2}$$
$$S_1 = r_1 + r_2, \tag{3}$$

where λ denotes the shadow price of the resource constraint. Applying the linear (inverse) demand function

$$p_t = \alpha - \beta(r_t) - \tau_t \tag{4}$$

with τ_t represting some unit tax on product sales, which will later be used to evaluate policy measures, gives the benchmark results:

$$r_1^{s*} = \frac{S_1}{2} - \frac{\tau_1 - \tau_2}{4\beta}, \tag{5}$$
$$r_2^{s*} = S_1 - r_1^{s*} = \frac{S_1}{2} + \frac{\tau_1 - \tau_2}{4\beta}. \tag{6}$$

[1]See for example Stern et al. (2006).

As there is no discount factor in the model the results follow the well known HOTELLING (1931) rule that prices rise by the discount factor. As long as $\tau_1 = \tau_2$, half of the resource is extrated in each period. The s superscript denotes the sole owner setting.

3 The basic setup

The basic structure of the model comprises two players $i = 1, 2$ competing over a single resource stock S_t in the two periods $t = 1, 2$. Each periods winner of the contest then extract some part of the resource r_{it} and sells it as a monopolist on a market depicted by a linear (inverse) demand function.[2] The main difference to ACEMOGLU ET AL. (2011) is that war is fought before extraction is made, this means the right to extract is contested not the extracted resource.[3]

Both players are risk neutral expected pay off maximizers. The conflict is modeled by a standard Tullock contest with the contest succes function

$$F_{it} = \frac{e_{it}}{e_{it} + e_{jt}} \tag{7}$$

which can be interpreted as the probality to win the contest. Exerting effort e produces constant marginal costs equal to γ for both players.

The model will be solved with two different methods. At first we will consider both players solving the game taking all reactions as given, which can be interpreted as a commitment to a specific plan. This is analogous to an open loop Nash equilibrium. Afterwards the game is solved via backward induction. This feedback strategy can be considered the equivalent of closed loop equilibrium of a differential game. Most of the simplicity of the model is owed to the desire to compute closed form solutions for the feedback strategies.

3.1 Commitment strategies

In the open-loop equivalent strategy case the four stages of the game are solved simultaneously by both players. Equilibrium results for the commitment case are marked with an c superscript. As, among other things, the resource constraint of the second period depends on who owned, and therefore extracted from, the stock in $t = 1$, control variables for $t = 2$ are superscripted with a state index $z = o, n$, where o denotes the case that player i owned the resource in $t = 1$. This leads to the following objective function of the maximization problem:

$$\begin{aligned} E(\Pi_1) = & \quad F_{11}(e_{11})[p_1(r_{11})r_{11} + F_{12}(e^o_{12})p_2(r^o_{12})r^o_{12} - \gamma e^o_{12}] \\ + & \quad [1 - F_{11}(e_{11})][F_{12}(e^n_{12})p_2(r^n_{12})r^n_{12} - \gamma e^n_{12}] \\ - & \quad \gamma e_{11}. \end{aligned} \tag{8}$$

Control variables of the problem are the r^z_{it} and e^z_{it}. The solutions have to fulfill the resource constraints:

$$S_1 = r_{11} + r^o_{12}, \tag{9}$$

$$S_1 = r_{21} + r^n_{12}. \tag{10}$$

[2] This is qualitatively equivalent to a setting where the extracted water is an essential production input and the product is than sold.

[3] Abstracting from the obvious fact that ACEMOGLU ET AL. (2011) have a much more general setting, but therefore are unable to give closed form solutions.

The shadow prices are λ_1^o and λ_1^n respectively. Computing first order conditions is straightforward:

$$\frac{\lambda_1^o}{F_{11}(e_{11})} = p_1'(r_{11})r_{11} + p_1(r_{11}) = F_{12}(e_{12}^o)[p_2'(r_{12}^o)r_{12}^o + p_2(r_{12}^o)], \tag{11}$$

$$\lambda_1^n = (1 - F_{11})F_{12}(p_2'r_{12}^n + p_2), \tag{12}$$

$$\gamma = F_{11}'[p_1 r_{11} + F_{12}p_2 r_{12}^o - \gamma e_{12}^o] - F_{11}'[F_{12}p_2 r_{12}^n - \gamma e_{12}^n], \tag{13}$$

$$\gamma = F_{12}'p_2 r_{12}^o = F_{12}'p_2 r_{12}^n. \tag{14}$$

From theses first order conditions follows the symmetric Cournot-Nash equilibrium:

$$e_{i1}^{c*} = e_{j1}^{c*} = \frac{p_1 r_{i1}^*}{4\gamma}, \tag{15}$$

$$e_{i2}^{co*} = e_{j2}^{cn*} = \frac{p_2 r_{i2}^{o*}}{4\gamma}. \tag{16}$$

This is in line with the standard result of Tullock rent seeking that half of the rent is dissipated by contest effort. More Interesting is of course the extraction path of the resource:

$$r_{i1}^{c*} = \frac{S_1}{3} - \frac{\tau_1 - \frac{1}{2}\tau_2}{3\beta} + \frac{\alpha}{6\beta}, \tag{17}$$

$$r_{i2}^{co*} = r_{i2}^{cn*} = S_1 - r_{i1}^{c*} = \frac{2S_1}{3} + \frac{\tau_1 - \frac{1}{2}\tau_2}{3\beta} - \frac{\alpha}{6\beta}. \tag{18}$$

The first two noteworthy results of the paper can be obtained by comparing the equilibrium extraction paths dependence on the two tax rates with that of the benchmark solution.

The first result is, that for any combination of τ_1 and τ_2 period 1 (2) extraction is always greater (lower) in the uncertain setting than in the benchmark case, which means the extraction path is always steeper. Therefore it's obvious that the condition for less extraction in period 1 than 2 is severer in the uncertain setting. For r_{i1}^* to be less than $\frac{S_1}{2}$ it has to hold that $\tau_1 > F_{i2}\tau_2$.[4]

The second result is that for a given set of τ_1 and τ_2 a marginal increase of τ_2 leads to less intertemporal leakage from the second to the first period in the uncertain case compared to the benchmark.

3.2 Feedback strategies

As mentioned above, the feedback strategies are derived by backward induction of the game. The stages of the game are as follows:

1. Players choose e_{11} and e_{21},
2. Winning player chooses r_{11} or r_{21},
3. Players choose e_{12}^o and e_{22}^n (or e_{12}^n and e_{22}^o respectively),
4. Winning player chooses r_{12}^z or r_{22}^z with $z = o, n$.

Equilibrium results for the feedback case are marked with an f superscript.

[4]In the sole owner setting $\tau_1 > \tau_2$ is sufficient, while this is straightforward as well, as the sole owner case can be considered a special case with $F_{i2} = 1$.

Stage 4: The solution of the last stage is rather simple. Depending on the state of the world $z = o, n$, the winner of the contest maximizes $\Pi^z_{i2} = p_2 r^z_{i2}$ under the constraint $S^z_2 = r^z_{i2}$. Which means, the solutions are determined by the constraint and result as follows:

$$\begin{aligned} r^{fo*}_{12} = r^{fn*}_{22} &= S_1 - r_{11}, && (19)\\ r^{fn*}_{12} = r^{fo*}_{22} &= S_1 - r_{21}. && (20) \end{aligned}$$

Stage 3: The third stage is of equal (in)complexity. Given the optimal depletion strategy for stage 4 (deplete the remaining stock), the players maximize expected profit minus effort cost:

$$E(\Pi^{z*}_{i2} - C(e^z_{i2})) = F_{i2} p_2 r^{z*}_{i2} - \gamma e^z_{i2} \tag{21}$$

under no further constraints. Straightforward calculation leads to the well known Tullock reaction functions:

$$e^{o*}_{i2}(e^n_{j2}) = \left(\frac{e^n_{j2}}{\gamma} p_2 r^{o*}_{i2}\right)^{\frac{1}{2}} - e^n_{j2}, \tag{22}$$

$$e^{n*}_{i2}(e^o_{j2}) = \left(\frac{e^o_{j2}}{\gamma} p_2 r^{n*}_{i2}\right)^{\frac{1}{2}} - e^o_{j2}. \tag{23}$$

In combination with (19) and (20) equilibria are:

$$e^{fo*}_{i2} = e^{fn*}_{j2} = \frac{p_2 r^{o*}_{i2}}{4\gamma} \text{ with } r^{o*}_{i2} = S_1 - r_{i1}, \tag{24}$$

which is again the standard result regarding the rent dissipation.

Stage 2: A little bit more complex and interesting is the solution of the extraction strategy for period one. After the first contest is resolved, the winnig player has to decide on the extraction rate, taking into account the effect on the maximized expected period two profit and effort costs. The main difference to a commitment strategy now is that the effort reaction of the opponent is not taken as given. The objective function therefore is:

$$\Pi_{i1} + \mathrm{E}(\Pi^{o*}_{i2} - C(e^{o*}_{i2})) = p_1(r_{i1}) r_{i1} + F_{i2}(e^{o*}_{i2}, e^{n*}_{j2}) p_2(r^{o*}_{i2}) r^{o*}_{i2} - \gamma e^{o*}_{i2} \tag{25}$$

The resource constraint has not to be taken into account explicitly, because r^{o*}_{i2} is actually a function of r_{i1}. The first order condition looks slightly different in comparison to the commitment case:

$$p'_1 r_{i1} + p_1 = F_{i2}(p'_2 r^{o*}_{i2} + p_2) + p_2 r^{o*}_{i2} \underbrace{\left[F'_{i2}\frac{\partial e^{o*}_{i2}}{\partial r_{i1}} - F'_{i2}\frac{\partial e^{n*}_{j2}}{\partial r_{i1}}\right]}_{=0 \text{ for } e^{o*}_{i2} = e^{n*}_{j2}} + \gamma \frac{\partial e^{o*}_{i2}}{\partial r_{i1}}. \tag{26}$$

Plugging the relevant partial derivatives in the first order condition gives:

$$p'_1 r_{i1} + p_1 = \left[F_{12}(e^{o*}_{i2}, e^{n*}_{j2}) - \frac{1}{4}\right][p'_2 r^{o*}_{12} + p_2], \tag{27}$$

which deviates from the commitment case by the $\frac{1}{4}$ subtrahend on the right hand side. This leads to the symmetric Cournot-Nash equilibrium with $F_{12}(e^{o*}_{i2}, e^{n*}_{j2}) = \frac{1}{2}$:

$$r^{f*}_{11} = r^{f*}_{21} = \frac{S_1}{5} - \frac{\tau_1 - \frac{1}{4}\tau_2}{\frac{5}{2}\beta} + \frac{3\alpha}{10\beta}. \tag{28}$$

Stage 1: In the first stage, the players choose effort "again", in this case to maximize expected payoff over both periods taking all reations into account. The objective function therefore is:

$$
\begin{aligned}
E(\Pi_i) = & \quad F_{i1}(e_{i1})\left[p_1(r^*_{i1})r^*_{i1} + F_{i2}(e^{o*}_{i2}, e^{n*}_{j2})p_2(r^{o*}_{i2})r^{o*}_{i2} - \gamma e^{o*}_{i2}\right] \\
& + \; [1 - F_{i1}(e_{i1})]\left[F_{i2}(e^{n*}_{i2}, e^{o*}_{j2})p_2(r^{n*}_{i2})r^{n*}_{i2} - \gamma e^{n*}_{i2}\right] \\
& - \; \gamma e_{i1}
\end{aligned}
\tag{29}
$$

Computing the first order conditions is here straightforward again, as none of the equilibrium strategies are functions of the period one efforts:

$$
F'_{i1}[p_1 r^*_{i1} + \underbrace{F_{i2}(e^{o*}_{i2}, e^{n*}_{j2})p_2(r^{o*}_{i2})r^{o*}_{i2} - \gamma e^{o*}_{i2} - F_{i2}(e^{n*}_{i2}, e^{o*}_{j2})p_2(r^{n*}_{i2})r^{n*}_{i2} - \gamma e^{n*}_{i2}}_{\Delta\Pi_i(e^{o*}_{i2}, e^{n*}_{i2}, e^{o*}_{j2}, e^{n*}_{j2}, r^{o*}_{i2}, r^{n*}_{i2})}] = \gamma. \tag{30}
$$

The difference of the two possible second period expected profits $\Delta\Pi_i$ could, as all equilibrium values of the denoted controls are just functions of the period one extraction rates, actually just be expressed as a function of those $\Delta\Pi_i = \Delta\Pi_i(r^*_{i1}, r^*_{j1})$ and what is more important, it vanishes for $r^*_{11} = r^*_{21}$. The structure of the reaction functions therefore differs only by an irrelevant term from those above:[5]

$$
e^*_{i1}(e_{j1}) \quad = \quad \left[\frac{e_{j1}}{\gamma}\left[p_1 r^*_{i1} + \underbrace{\Delta\Pi_i(r^*_{i1}, r^*_{j1})}_{=0 \text{ for } r^*_{11}=r^*_{21}}\right]\right]^{\frac{1}{2}} - e_{j1}. \tag{31}
$$

The equilibrium values of the efforts represent therefore again the well known result regarding the rent dissipation:

$$
e^{f*}_{i1} = e^{f*}_{j1} \quad = \quad \frac{p_1 r^*_{i1}}{4\gamma}. \tag{32}
$$

While the structure of the feedback results looks rather similar to the commitment case they produce two more noteworthy findings. The first noteworthy result is that a given resource stock S_1, which is small enough to produce meaningful solutions in both strategy settings,[6] and a given set of tax rates, the depletion path is always steeper in the feedback setting. This effect is driven by the fact that the players take into account the second periods effort cost when deriving optimal period one extraction.

The second noteworthy finding is resulting effort exercised by the players. While in both settings the sum of each periods effort equals half of the afterwards enjoyed rent, these rents have a different structure. The sums therefore differ between the settings.

The main results of the paper can be summarized in three propositions:

Proposition 1. *For a given set of τ_1, τ_2 and $S_1 < \frac{\alpha}{\beta} - \frac{\tau_1+\tau_2}{2\beta}$ it holds that:*

$$
r^{f*}_{i1} > r^{c*}_{i1} > r^{s*}_{1}.
$$

[5]This is of course only true for this symmetric setting.

[6]Meaningful in the sense that one is in a range of S_1 where the players prefer more resources to less, which means shadow prices are positive.

This reproduces LONG (1975)'s results that insecurity in the property rights produce steeper extraction paths, while this paper adds the insight that an endogenous threat[7] might lead to even severer divergence from the Hotelling path.

The second proposition orders the expected payoffs of the players:

Proposition 2. *For a given set of* τ_1, τ_2 *and* $S_1 < \frac{\alpha}{\beta} - \frac{\tau_1+\tau_2}{2\beta}$ *it holds that:*

$$\Pi(r_1^{s*}, r_2^{s*}) > \sum_{i=1}^{2} E\left(\sum_{t=1}^{2}(\Pi_{it}(r_{it}^{c*}) - C(e_{it}^{c*}))\right) > \sum_{i=1}^{2} E\left(\sum_{t=1}^{2}(\Pi_{it}(r_{it}^{f*}) - C(e_{it}^{f*}))\right).$$

While from a sustainability perspective the preference order should be the same, as a faster extraction path then becomes even more unfavorable, a peacekeeper might object. The reason is summarized in the third proposition:

Proposition 3. *For a given set of* τ_1, τ_2 *and* $S_1 < \frac{\alpha}{\beta} - \frac{\tau_1+\tau_2}{2\beta}$ *it holds that:*

$$\sum_{i=1}^{2} E\left(\sum_{t=1}^{2}(C(e_{it}^{c*}))\right) > \sum_{i=1}^{2} E\left(\sum_{t=1}^{2}(C(e_{it}^{f*}))\right).$$

War efforts, and therefore war costs, are higher in the commitment case compared to the feedback case.[8] While the channel is different this result is similar to that of AMEGASHIE/RUNKEL (2008).

What can be set as well is, that a marginal increase of τ_1 (τ_2) leads *ceteris paribus* to an deceleration (acceleration) of the extraction path and therefore a shift of war effort to the future (present).

4 Policy implications

From a policy perspective the implications depend as always on the importance one assigns to possible targets. What was shown in this paper is that there might be something like tradeoff between preservation targets and pacification strategies. If a society or institution has the option to adjust it's rules in a way that resource usage strategies are pushed to commitment it has to take into account the possibly higher rent seeking costs in the future.

5 Conclusion

The papers analysis has demonstrated that there are additional linkages between water use and (civil) wars. On the one hand, the correlation between war and ground water scarcity is not clear cut, on the other welfare ranking in this simple setting is still straightforward. To get a more detailed insight, the results should be generalized and cross effects to other sectors should be incorporated in a more general equilibrium setting. These extensions are the subject of current research.

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[7]The commitment case actually reproduces the results of an exogenous threat.

[8]Effort would be even higher in a single contest that would determine a sole owner for both periods.

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