Divide and Conquer: Noisy Communication in Networks, Power, and Wealth Distribution

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Summary

In a society composed of a ruler and its citizens: what are the determinants of the political equilibrium between these two? This paper approaches this problem as a game played between a ruler who has to decide the distribution of the aggregate income and a group of agents/citizens who have the opportunity to revolt if they are unhappy with the distribution. Nevertheless, if too few revolt, the agents become defeated and receive zero consumption, while a successful revolt increases the consumption level of the rebels whereas the ruler receives nothing. Coordinated action by citizens is possible because they form nodes in a communication network. However, communication through the network is noisy, which removes common knowledge about the endowments and could preclude the emergence of collective action among citizens. In this paper, I argue that the network structure and the noise level are determinants of the political equilibrium and wealth distribution. The model explains how the ruler could use propaganda, cooptation and repression to increase his expected utility. The formalization of the game is accomplished using such concepts as p-beliefs and p-dominant strategy (Monderer and Samet, 1989, and Morris and Shin, 2002). Finally, I illustrate the model by applying it to cases in Nigeria and Zaire/Congo.

Keywords: Non cooperative Games, Networks, Political economy, Development, Political processes, Rent-seeking, Conflict, Alliances, Coalitions

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I. INTRODUCTION

In a society composed of a ruler and its citizens: What are the determinants of the political equilibrium between these two? In this introduction, I first argue that this question is relevant in economic theory, especially in development economics, and that understanding the origin of the distribution of political power in the society could shed light on reasons for economic backwardness. Secondly, I present the key features of my game-theory-based model, which explains that the political equilibrium in a society depends on the characteristics of the a communication network that connects its citizens, as well as the noise present in such network. Although the model is simple, it enables us to analyze how propaganda, repression, and cooptation could be used by the ruler to enhance his political power, and how income distribution depends on the political equilibrium.

There is a growing consensus on the importance of institutions and technology in order to explain the striking differences in per capita income between developed and underdeveloped countries. Enforcing property rights, the rule of law and adopting of the best technology available seem to provide many explanations about the economic performance of a country[2]. Therefore, the question is: Why do underdeveloped countries fail to choose better institutions and/or adopt the appropriate advanced technology?

Several authors have formulated an answer. Parente and Prescott (1997) developed a model where a country protects monopoly rights via regulation, making it difficult and costly for potential entrants to enter into the protected industry with better technology, which, in effect, impedes the growth of the economy. This is an example of

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[2] For example, Rodrik and Subramanian (2003), Parente and Prescott (1997) and Sala -I-Martin (1997), Acemoglu (2000 and 2003) among many others.

what Acemoglu (2000) calls the "economic losers hypothesis" in which interest groups block the adoption of new technologies or better institutions to protect their economic rents. However, as correctly noted by Acemoglu, these models assume that such interest groups have the political power to block reforms. The question is then: Why cannot other citizens "block the blockade", and impose institutional reforms or the introduction of better technologies, if that would benefit the majority? In other words, where does the distribution of political power among members of a society come from and when does such distribution preclude technological or institutional reforms?

Alternatively, other authors propose the "political losers hypothesis" (Acemoglu (2000) Bush and Muthoo, 2002). In the Acemoglu model, the elite could loss political power due to technological advances. Therefore, the argument is that if the elite maintain political power after reform, they could use that advantage to extract the gains of the technological progress. Thus, if the elite defend the status quo, it must indicate that reforms threaten their political power. In the Busch-Muthoo model, institutional changes adopted by a society on some topic could hinder the bargaining power of the elite in other issues. However, it is only assumed in both models that technological or institutional change diminishes political power of the elite. That is, no reasons are given as to why this is so. It is obvious that to understand why and when technological and/or institutional changes modify the political equilibrium of society, we need a theory capable of explaining the origin of such equilibrium.

We also found political assumptions in Acemoglu and Johnson, 2003, where they distinguish between "property rights institutions", which aim at precluding expropriations by the government or the elite to citizens, and "contracting institutions", which allow contracts among citizens. These authors found (using a game theory model and instrumental variable approach) a first order negative effect of the lack of "property rights institutions" on long-term growth. Meanwhile, "contracting institutions" only seemed to matter for financial intermediation methods. If the absence of security on property of citizens hinders economic growth, it is important to understand the political power distribution which allows expropriations by the elite or the government.

There are also political assumptions in Mancur Olson's (1993, 2000) model on the origin of the state, where an itinerant bandit decides to settle down, seizes and holds a territory, and becomes a respected ruler of its inhabitants. Since the ruler wants to maximize his income, which is the product of the tax rate and the tax base, he has to take into account the incentive-distorting effect of taxation. Although in this model the ruler holds total political power, he does not want to expropriate his subordinates completely. Thus, he will set a sufficiently low tax rate so as to leave them with an adequate incentive to produce. Moreover, it is in his interest to provide public goods, such as enforcing property rights and private contracts among his subordinates, and providing them peace and order. Again, the key assumption about the origin of political power that the ruler holds still needs an explanation.

Giving importance to property rights, economic theorists have tried to understand their origin and evolution. Skaperdas (1992), for example, model two individuals who receive an endowment as initial resources. Each agent has to decide how much of this endowment should be devoted to produce consumption goods and how much to produce "arms". The quantity of arms of each agent defines his probability of winning a war, where the winner would receive all available consumption in the economy. The model provides many insights in the relationship between power (measured as the probability of winning a war) and property rights. However, it is worth to recall David Hume's words "Nothing appears more surprising to those who consider human affairs with a philosophical eye, than the easiness with which the many are governed by the few?"[3]. This is the political equilibrium we are interested in, where the problem of collective action –specially by the governed- is relevant.

To approach these issues, we develop a model with a ruler and *n* citizens, who have a utility function *U(.)* that depends only on the consumption of a unique kind of good available in this economy. The citizens are the nodes in a communication network. The structure of the network is exogenous and could be understood as the result of geographic restrictions (such as natural barriers among villages or natural links such as navigable rivers) or cultural conditions (different languages, castes or social classes, regionalism, and social norms of inclusion and exclusion) and the ruler's political actions (repression). People can send information through the network, but this communication could be defective in the following sense: If we assume that the consumption level of an agent has two possible states, *H* and *L*, a person linked to that agent would observe the true state with probability a and the other with probability 1-a. The information about that agent's consumption will travel through the network, suffering the possibility deformations at every link. We will call 1-a the "noise level" and a the "channel capacity". The reasons for such distortion could be cultural (such as norms against "flaunting one's wealth" and lack

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[3] (David Hume, "Of the First Principles of Government", 1758, p. 32 of the 1987 edition, cited by Basu, 2000)

of trust among citizens[4] or among ethnic groups) and represent a simplification of the noise present in every communication process.[5]

The total amount available of the consumption good is exogenous. By this assumption, in this model the extraction by the government will depend only on the political equilibrium since there is no room for an incentive-distorting effect of the ruler's extraction as in Olson's model. It is the ruler's job to distribute the total amount of consumption good, which is equal to $T > nH$ for some $H > 0$, among the citizens and himself. To do so, the ruler and the citizens play a one-shot two-stage allocation game. In the first stage the government could use propaganda to change the agent's priors[6], and/or repression to change the communication network, eliminating a subset of citizens. Finally, the ruler has to allocate one of two consumption levels (H or L, $0 < L < H$) to citizens who survive the repression. The leftover will be the ruler's consumption.

The ruler, of course, would like to assign L to as many citizens as possible, but after the allocation is made it is the citizens' move. Essentially, every agent has to decide, privately and simultaneously, whether to revolt against the ruler or not. If a given agent decides not to rebel, his consumption level would be whatever is assigned by the regime. On the other hand if at least $\hat{f}$ other agents also decide to revolt, they will defeat the ruler and achieve an individual consumption level of M, where $0 < L < M < H$, while the ruler receives zero consumption. If less than $\hat{f}$ agents revolt, then the regime will prevail and maintain its original consumption, while each rebel gets zero utility. This means we are assuming that the goods the defeated rebels would consume will be thrown away; the

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[4] The lack of trust among two persons belonging to different ethnic groups has been documented by Alesina and La Ferrara (2002).

[5] See Shannon 1948.

[6] Agents will use their priors to make a decision, so it could make sense for the ruler to try to change them.

government, therefore, would not receive any benefit from a defeated uprising.[7] On the other hand, assuming only uprising agents will benefit from a triumphant revolution, we could disregard the "free rider" effect and focus only on the consequences in the absence of common knowledge in wealth distribution.

In principle, if at least $\hat{f}$ agents receive a consumption level of L, it is in their interest to revolt. In fact, if this happens in a perfect information environment, there will be two Nash Equilibria in the second stage: one where underprivileged agents rebel and one where nobody does. In this paper, we focus on the analysis of the former case, because it is difficult to imagine how a ruler could rely on the latter when making decisions. Since the agents obtain their information about one another through a noisy communication network, no agent knows with certainty the payoff of any other agent. This complicates the emergence of collective action but does not make an uprising impossible[8].

We find that the ruler's maximum expected utility depends on the channel capacity and, more interestingly, on the network structure, and on the cost of propaganda and repression. In particular, the lower the channel capacity and the less connected the network, the higher the expected utility of the ruler and, in some interesting cases, the higher the number of deprived citizens. In addition, we found that it could be in the government's interest to provide H to some citizens, in particular, those who have relatively more connections – we call this cooptation.

We use this model, first, to reflect on the determinants of political equilibrium in a society divided in a ruler and its citizens and on how rent-seeking rulers could use

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[7] This is equivalent to assuming that when the government is able to defeat an uprising (i.e. when fewer than $\hat{f}$ agents revolt), it has to expend L to defeat a rebel.

[8] This is formalized in chapter II.

propaganda, repression, and cooptation to increase its political power and, therefore, its expected utility. We illustrate the model with countries such as Congo and Nigeria

The paper is organized as follows: Section II develops and explains the model; Section III presents two examples, and Section IV applies the model and discusses the results.

II. THE MODEL

In this section, we introduce some notation and formalize the game. First, we present a simplified version of the game where the government's set of strategies include only different ways to allocate the aggregate income among citizens (i.e. propaganda and repression are not allowed). The citizens will have the option to attack or not. This basic game is analyzed in a complete information environment. Then, we explain how the game works in an incomplete-asymmetric information setting, finding the conditions for the emergence of a revolt against the ruler, and how this shapes the ruler's best response. Finally, we study the entire game allowing the government to use repression and propaganda in an incomplete –asymmetric information environment.

II.1.The basic game

We consider a set of *n+1* agents: agent 0, the ruler, and the citizenry consisting of the set $N = \{1,..., n\}$. Each agent has an increasing and concave utility function $U(x)$, which depends only on his consumption $x\ (x \geq 0)$. We normalize the utility function such that $U(0) = 0$.

Among these individuals there are bilateral and symmetric relationships called communication links. We denote this by ij, the link between *i* and *j*. We use $\Gamma^N = \{ij / i \in N, j \in N\}$ to denote the set of all possible links among agents in N and Γ to denote a set of links (i.e. $\Gamma \subseteq \Gamma^N$). A communication network is a non-oriented graph (N, Γ) where the players are the nodes, connected by bilateral links in Γ. The shortest path between two agents i and j is called the geodesic,[9] and the number of links along such a path is called the degree of separation between i and j, noted as $d(ij)$. We consider only networks (N, Γ) that interconnect every pair of agents in N. The network structure is common knowledge among the agents.

Now we define a one-shot, two-stage "allocation game." In the first stage, the ruler distributes the total amount of consumption good, exogenously set as T $(T > nH)$, assigning some non-negative amount X_i of the good to each citizen i, where $X_i \in Q = \{H, L\}$, $0<L<H$. Hence, the set of strategies for agent zero is $S_0 = \left\{\{X_i\}_{i=1,2,...,n}, X_i \in Q\right\}$. Note that in principle, the ruler would be able to allocate H to every citizen and still receive positive consumption.

In the second stage, it is the citizens' turn to play. Each one has two available strategies: $S_i = \{A, C\}$ for $i = 1,2,...,n$, where C stands for "accept X_i and do not fight the ruler" and A stands for "do not accept X_i and attack the ruler." However, the outcomes will depend not only on the individual's decisions, but also on the decisions of other citizens. In particular, it is necessary that a coalition of at least $\hat{f} > 1$ individuals fight the ruler to defeat him. The number $\hat{f}$ is exogenous in this model, and represents the government's ultimate repressive capacity. If such a coalition arises, the ruler will in fact be defeated and get a consumption level of zero. Then every member of the triumphant partnership will get a new allowance of M, where $0<L<M<H$, and hence the utility for all members in the winning group would be $U(M)$. Although it is true that the reward M

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[9] If there is more than one distinct geodesic from i to j, we choose one randomly for driving the information from i to j and vice versa. Thus, we always talk about "the" geodesic connecting two agents. Agents will only rely on information coming through a geodesic.

should depend on the size of the winning coalition, we keep it exogenous for simplicity. Meanwhile the citizens who did not participate in the revolt (either triumphant or defeated) would not be affected, keeping their utility at $U(X_i)$. We assume M is such that $\frac{U(Z)}{U(M)} > 1/2$.[10] On the other hand, if the attacking coalition has fewer than $\hat{f}$ members, the ruler would prevail and the members of the defeated group will lose their entire endowment, which would be thrown away, and have a utility of 0. Therefore, for the citizens, the payoffs are as follows:

$$U_i = \begin{cases} U(X_i) \, if \quad C \\ 0 \quad if \quad A and \quad f < \hat{f} \\ U(M) \quad if \quad A \quad and \, f \geq \hat{f} \end{cases}$$

Each citizen would choose his strategy privately and simultaneously. Of course, the players would maximize their expected utility. The ruler's utility will be $U\left(T - \sum_{i=1}^{n} X_i\right)$ if not defeated and zero if defeated.

We can see that if the endowments $\{X_i, i = 1,2,..., n\}$ are common knowledge, and $f \geq \hat{f}$ citizens receive $X_i = L$, then there is a Nash equilibrium where a coalition arises and defeats the ruler, since it is common knowledge among these f citizens that it is in everybody's interest to fight the ruler and get a utility of $U(M) > U(L)$. Hence, in this situation, the best the ruler could do is to assign H to $n - \hat{f} + 1$ citizens and L to the other $\hat{f} - 1$ agents. In this way, $n - \hat{f} + 1$ citizens would receive a utility $U(H)$ and would not participate in any rebellion, while the remaining agents would receive a utility of $U(L)$,

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[10] We will see that this assumption facilitates the calculations.

but cannot consolidate a coalition strong enough to defeat the ruler.[11] Hence, agent zero would ensure a utility equal to $U\left(T-(n-\hat{f}+1)H-(\hat{f}-1)L\right)$. In this perfect-information environment, if at least $\hat{f}$ citizens receive $X_i = L$, there is also a Nash equilibrium where nobody challenges the ruler. Such a Nash equilibrium could allow the ruler to assign $X_i = L$ to everybody, but we do not find such a case interesting because, again, it is difficult to imagine how a ruler can rely on such an equilibrium to define his best response.

II.2. The incomplete information game

We assume that endowment X_i is only known by i itself and by the ruler, and that to acquire knowledge about the endowments of others, each agent has to rely on the communication network. This notation will be useful: $\overline{X}_i = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ if $X_i = H$, and $\overline{X}_i = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$ if $X_i = L$. Now suppose, additionally, that the communication in such a network is noisy, which means that if agent i has an endowment $X_i \in Q$, agent j (who is one link away from i) would receive a signal $\hat{X}_{ji}$, which is a random variable with distribution $\Pi\overline{X}_i$, where $\Pi = \begin{bmatrix} a & 1-a \\ 1-a & a \end{bmatrix}$.

Information containing endowment of i would travel through the network suffering possible distortions at every link. For example, consider an agent r and suppose a geodesic from i to r is $\{ij, jr\}$. This means that j receives an unclear message $\hat{X}_{ji}$ about X_i and r receives an unclear signal $\hat{X}_{ri}$ about the information j has received about X_i. Then the

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[11] We assume that no re-distribution of endowments (in any situation) is possible among any group of agents, which is logical in this non-cooperative environment.

distribution of $\hat{X}_{ri}$ is $\Pi^2 \overline{X}_i$. In general, the signal $\hat{X}_{si}$ an agent s receives about the endowment of i, given the degree of separation between them, *d(si)*, has the distribution $\Pi^{d(si)} \overline{X}_i$. Note that the journey of the signal through a geodesic is a Markov chain. In addition, we assume signals with different origins are stochastically independent, that is $\left\{\hat{X}_{ij}\right\}_{i\in N}$ and $\left\{\hat{X}_{ik}\right\}_{i\in N}$ are independent if $j \neq k$.

The calculation would be easier if we assume $a \geq 1/2$. Then Π would have two useful properties: $\prod^k \to \begin{bmatrix} 1/2 & 1/2 \\ 1/2 & 1/2 \end{bmatrix}$ when $k \to \infty$, and using the notation $\Pi^k = \begin{bmatrix} a_{11}(k) & a_{12}(k) \\ a_{21}(k) & a_{22}(k) \end{bmatrix}$ we have $a_{11}(k) > a_{11}(k+1) \geq 1/2, k = 1,2..$ .This last property implies that the information the signal carries decreases monotonically with each link it travels through. If *a=1*, there would exist common knowledge of endowments. On the contrary, if the noise level is the highest possible (i.e.½), there is a higher possibility that the signals would not carry any useful information because the agents would not be able to actualize their priors after receiving the signals (see below).

Given the communication structure, endowments $\{X_i\}_{i=1}^n$ define the probability distribution of signals that each agent would receive. To be precise, we define a probability space $\left\{\Omega, \Re, \hat{P}\right\}$ where, using the convention $\hat{X}_{ii} = X_i$, we have:

$$\Omega = \left\{ w = \left\{\hat{X}_{ij}\right\}_{i=1,\dots,n}^{j=1,\dots,n} ; \hat{X}_{ij} \in Q \right\}$$

The sigma-algebra $\Re$ is the power set of Ω , $\Re = \{\Lambda / \Lambda \subset \Omega\}$, and $\hat{P}$ is the probability distribution $\hat{P}\left(\left\{\hat{X}_{ij}\right\}_{i=1,\dots,n}^{j=1,\dots,n} \middle| \left\{X_i\right\}_{i=1,\dots,n} ; a; (\Gamma, N) \right)$. We have added parameters a and (Γ, N) as arguments of $\hat{P}$ to emphasize the dependence of this probability on the noise level and the network structure, respectively. The calculations of $\hat{P}$ is described in Appendix 1. Note that this probability is known only to agent zero, and is different from the citizens' prior probability, defined as follows.

Assume an incomplete information game $\left\{\Omega, (P_i)_{i=1}^{n}, (\Psi_i)_{i=1}^{n}, (U_i)_{i=1}^{n}\right\}$, where P_i is the prior probability distribution of i on omega, defined in the same way as $\hat{P}$, which depends on the endowment distribution $\{X_i\}_{i=1}^{n}$, the channel capacity *a*, and the network structure (Γ, N). However, the problem is that citizen i does not know the endowments, except his own, so i has to rely on a prior about others agents' endowments. Following Morris and Shin (2002), we assume such prior distribution is uniform,[12] [13]that is:

$$P_i(X_j = L) = P_i(X_j = H) = 1/2, \forall j = 1,2..n, j \neq i\,.$$

Ψ_i is player i 's partition of the state space Ω. If $s \subset N \setminus \{i\}$ and $\Psi_i^s = \left\{ \left\{ \hat{X}_{kj} \right\}_{k=1,\dots,n}^{j=1,\dots,n} / \hat{X}_{kj} \in Q, \hat{X}_{ij} = L \quad if \quad j \in s\,, \hat{X}_{ij} = H \quad if \quad j \notin s \right\}$, then i 's partition would be: $\Psi_i = \left\{ \Psi_i^s, s \subset N \setminus \{i\} \right\}$. Since agent i only sees the signals he receives, $\left\{ \hat{X}_{ij} \right\}_{j=1}^{n}$, two events, ω and ω', are in the same set of his partition if they yield him the same collection of signals. We abuse the notation calling $\Psi_i(w)$ the set in i's partition to where

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[12] Morris and Shin (2002) call this prior "Laplacian", because it follows Laplace's "suggestion that one should apply a uniform prior to unknown events from the principle of insufficient reason." See *op cit* p.5 and 6.

[13] Later on (chapter II.3) we will relax this assumption to allow a priors ratio $\dfrac{P_i(X_j = H)}{P_i(X_j = L)}$ different from 1 and make it possible for the government to change it using propaganda.

ω belongs, hence $\Psi_i(w) = \Psi_i(w')$ if and only if ω and ω' are in the same set of i's partition.

Finally, $U_i : S \times \Omega \to R$ is player i's payoff function, with $S = S_0 \times S_1 \times .. \times S_n$ and the strategies and payoffs described above.

II.3. The emergence of coalitions

Information that agents receive is incomplete (since every citizen receives just an imprecise signal about the other agent's endowment) and asymmetric (since each agent knows exactly its own endowment, but the signals could be different for each citizen). Thus, every agent can only infer the endowments and signals that his partners have received, and then he could conjecture the strategies they could adopt. So, it is clear that common knowledge about payoffs is lost in this game as long as $a < 1$. We have to understand how collective action could arise in such an environment. As Morris *et al* (1995), page 145, explain:

> When payoffs in a game are not common knowledge, the outcome depends not only on players' beliefs about payoffs, but also on their beliefs about others' beliefs about payoffs, and on their beliefs about others' beliefs about their own beliefs, and so ad infinitum.

To approach this problem, we use the concepts of *p*-belief operators created by Monderer and Samet (1989), and *p*-dominance and *p*-dominant equilibrium developed by Morris and Shin (1995 and 2002).

Morris and Shin (2002) define $|g|$ as a set of states in the incomplete information game where payoffs are given by g:

$$|g| = \left\{ w \in \Omega / U_i(s,w) = U_i\left(s, \left\{ \hat{X}_{kj} \right\}_{k=1,\dots,n}^{j=1,\dots,n} \right) = U_i\left(s, \left\{X_i\right\}_{i=1}^{n}\right) = g_i(s), \forall s \in S, i = 1,\dots,n \right\}$$

We could say $U_i\left(s,\{\hat{X}_{kj}\}_{k=1,\dots,n}^{j=1,\dots,n}\right)=U_i\left(s,\{X_i\}_{i=1}^{n}\right)$ because payoffs depend only on strategies and endowments. A pure strategy Nash equilibrium s^* of a complete information game, g, is defined as a p-dominant equilibrium if, for all i s_i^* is i´s best response[14] whenever he assigns a probability of at least p to his opponents, choosing according to s^*:

$$\sum_{s_{-i}\in S_{-i}} \lambda(s_{-i})g_i(s_i^*,s_{-i}) \geq \sum_{s_{-i}\in S_{-i}} \lambda(s_{-i})g_i(s_i,s_{-i})$$

for all $i=1,\dots,n;$ $s_i \in S_i$, and for all λ probability distributions on S_{-i} such that $\lambda(s_{-i}^*)\geq p$.

We need to recall the definition of p-belief operators. Let an event be $E\subset\Omega$. The event "i p-beliefs E" is noted as $B_i^p(E)$ and defined as $B_i^p(E)=\{w\in\Omega/P_i(E\mid\Psi_i(w))>p\}$. The event "$E$ is p-believed" is $B^p(E)=\bigcap_{j\in N}B_j^p(E)$. Finally, event E is a common p-belief at state w if it is p-believed that it is p-believed, and so on, up to an arbitrary number of levels. We note the set of such w as $C^p(E)$. At this point we need:

Lemma 4.2 from Morris and Shin (2002). If s^* is a *p-dominant* equilibrium of the complete information game g, then every incomplete information game $\left\{\Omega,(p_i)_{i=1}^n,(\Psi_i)_{i=1}^n,(U_i)_{i=1}^n\right\}$ has an equilibrium where s^* is played with probability 1 on the event $C^p(|g|)$.

Now, we have the instruments to solve our game. We would use backward induction in the following way. We could assume that the ruler has defined $\{X_i\}_{i=1}^n$, where at least $\hat{f}$ citizens receive *L*. The goal of the regime is to measure the event where a group

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[14] As usual we note $S_{-i}=S_0\times S_1\times..\times S_{i-1}\times S_{i+1}\times..\times S_n$ and $s_{-i}=\{s_0,s_1,..,s_{i-1},s_{i+1},..,s_n\}$

of at least $\hat{f}$ citizens will play “attack” with probability one. Using that measure, the ruler could calculate the expected utility that such an allocation $\{X_i\}_{i=1}^{n}$ would yield him. Doing this exercise for each possible allocation, the government could choose its best response.

To proceed, we identify events that the ruler should count as “attacked by at least $\hat{f}$ agents”. First, note that in a perfect information game, “attack” for i receiving L and “do not attack” for i receiving H is a NE. Also, “attack” will be a best response for i only if $X_i = L$. The probability p that agent i assigns to the event “at least $\hat{f}-1$ other citizens will attack” is p>1/2, because the expected utility of attacking is:

$$pU(M)+(1-p)U(0) = pU(M) \geq U(L),$$

and we assumed that $\dfrac{U(L)}{U(M)} > 1/2$. Second, note that although revolts of more than $\hat{f}$ citizens are possible, from the ruler’s point of view, it is enough to take into account the events where $\hat{f}$ citizens play “attack”.[15] From now on, s will denote $\mathrm{s} \subset N$ and $\#(\mathrm{s}) = \hat{f}$.

Third, note that if we are trying to identify events where a specific group s of deprived citizens would revolt, we only have to consider events where $\hat{X}_{ij} = L \quad \forall i, j \in \mathrm{s}$. To see this, consider the case where some $s \in \mathrm{s}$ receives a signal H about $k \in \mathrm{s}$, so $\hat{X}_{sk} = H$. Then, we know: $P(X_k = L | \quad \hat{X}_{sk} = H) = a_{21}(d(sk)) < 1/2$. This means that the probability agent s would assign to the event “everybody in s receives L” is less than

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[15] If f citizens, $f > \hat{f}$ “attack” in event w, obviously, $\hat{f}$ agents will play attack on such event w. The results, from the ruler’s point of view, would be the same.

half. If that is the case, "attack" will never be a p-dominant strategy for s, since for it to be the case, it is necessary that p>1/2.

Therefore, we could focus on event $E = \{w \in \Omega / \hat{X}_{kj} = L; k, j \in s\}$. In this event, every citizen in s gets L and also receives a signal $\hat{X}_{kj} = L$ from every member of the group. We want to find the condition for E to be common p-believed by s. This is stated in the next lemma.

Lemma 1. The necessary and sufficient condition for $E = \{w \in \Omega / \hat{X}_{ik} = L; k, i \in s\}$ being common p-believed in E (i.e. $C^p(E) = E$) is $\hat{P}(\hat{X}_{tk} = L \mid X_k = L; k, t \in s) \geq p$. (See proof in Appendix 2). We are ready to say when a revolt of $\hat{f}$ citizens will occur.

Proposition 1. If for some $s \subset N$ with $\hat{f}$ members, where $X_i = L$ for $i \in s$, it is true that $\hat{P}(\hat{X}_{tk} = L \mid X_k = L; k, t \in s) \geq p$, for some $p \geq \dfrac{U(L)}{U(M)}$, then "attack" will be played with probability 1 for agents in s in event $E = \{w \in \Omega / \hat{X}_{ik} = L; k, i \in s\}$.

To prove this, we first note that if for some $s \subset N$ with $\hat{f}$ members $X_i = L$ for $i \in s$, then in a complete information game, $i \in s$ will "attack" in one of the two NE. For some $p \geq \dfrac{U(L)}{U(M)}$, this would also be a p-dominant equilibrium. Using the assumption $\hat{P}(\hat{X}_{tk} = L \mid X_k = L; k, t \in s) \geq p$, Lemma 1, and Lemma 4.2 from Morris and Shin (2002), we can conclude that "attack" will be played with a probability 1 for s in the event $E = \{w \in \Omega / \hat{X}_{ik} = L; k, i \in s\}$, completing the proof.

We are ready to tell the ruler the events when a coalition of at least $\hat{f}$ members will "attack", given endowments $\{X_i\}_{j\in N}$. Such event is:

$$\Phi = \left\{ w \in \Omega / \exists s \ \forall i \in s \quad : \left\{\hat{X}_{ij} = L\right\}_{j\in s}, \hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; t,k \in s\right) \geq p, p \geq \frac{U(L)}{U(M)} \right\}$$

Agent zero is maximizing his expected utility:

$$P.1 \quad \underset{\{X_i\}_{i=1}^{n}}{Max} \quad \left[1 - \hat{P}\left(\Phi; a, (\Gamma, N), \{X_i\}_{i=1}^{n}\right)\right] U\left(T - \sum_{i=1}^{n} X_i\right) \qquad s.t\ X_i \in Q \quad i = 1,2..n$$

This maximum exists, because the set of possible allocations is finite. Given the two-stage structure of this game and how citizens define their strategies once the allocation is made, the ruler could use backward induction to find the best strategy.

We note $\tilde{U}((\Gamma, N), a)$ as the maximum expected utility the ruler could obtain given the network and the channel capacity. The next corollary explains that the more (less) connected the network and/or the higher (lower) the channel capacity, the lower (higher) the expected utility the ruler would obtain in this game.

Corollary 1: If $\Gamma_1 \subset \Gamma_2$ and $a_1 < a_2$, then:

$$\tilde{U}((\Gamma_2, N), a) \leq \tilde{U}((\Gamma_1, N), a) \text{ and } \tilde{U}((\Gamma, N), a_2) \leq \tilde{U}((\Gamma, N), a_1)$$

Proof: Let us assume that $\tilde{U}((\Gamma, N), a_2) > \tilde{U}((\Gamma, N), a_1)$, where $\{\tilde{X}_i\}_{i=1}^{n}$ is the allocation with a maximum at $\tilde{U}((\Gamma, N), a_2)$. That is:

$$\tilde{U}((\Gamma, N), a_2) = \left[1 - \hat{P}\left(\Phi; a_2, (\Gamma, N), \{\tilde{X}_i\}_{i=1}^{n}\right)\right] U\left(T - \sum_{i=1}^{n} \tilde{X}_i\right).$$

If we apply such allocation to a game with a lower channel capacity a_1, we would obtain a set of events where "attack" will be played by fewer citizens $\hat{f}$ when the channel capacity is lower:

$$\Phi_1 = \Phi\left(a_1, (\Gamma, N), \left\{\tilde{X}_i\right\}_{i=1}^n\right) \subset \Phi\left(a_2, (\Gamma, N), \left\{\tilde{X}_i\right\}_{i=1}^n\right) = \Phi_2 ,$$

so, if $w \in \Phi_1$, then $\exists s \subset N$ such that $\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k, t \in s\,; (\Gamma, N), a_1\right) \geq p$. Hence, for the same group of citizens it is also true that

$$\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k, t \in s\,; (\Gamma, N), a_2\right) \geq p \text{, that is } w \in \Phi_2 .$$

Furthermore, $1 - \hat{P}(\Phi_1; a_1) > 1 - \hat{P}(\Phi_2; a_2)$, therefore:

$$\left[1 - \hat{P}(\Phi_1; a_1)\right] U\left(T - \sum_{i=1}^{n} \tilde{X}_i\right) > \left[1 - \hat{P}(\Phi_2; a_2)\right] U\left(T - \sum_{i=1}^{n} \tilde{X}_i\right)$$

Using our initial assumption, this means that $\left[1 - \hat{P}(\Phi_1; a_1)\right] U\left(T - \sum_{i=1}^{n} \tilde{X}_i\right) > \tilde{U}\left((\Gamma, N), a_1\right)$.

However, this is not possible since the right-hand side of the inequality represents the maximum utility level a ruler could obtain with channel capacity a_1. The proof for different network connectivity is similar. This concludes the proof of corollary 1.

The next corollary should also be noted:

Corollary 2: For any network structure[16] (Γ, N) and any group s (with $\hat{f}$ members) that receive an allocation of Z, there is a noise level $1 - a$ such that the "attack" will be played by agents in s with probability 1 on event $E = \left\{w \in \Omega / \hat{X}_{ik} = L; k, i \in s\right\}$. On the other

---

[16] Recall, we assume that the network is fully connected, i.e. there is always a geodesic connecting any pair of agents.

hand, there is always a noise level $1-a$ such that the “attack” will never be played by agents in s .

Proof: For any fully connected network structure (Γ, N) and any coalition s of $\hat{f}$ members receiving an allocation of L, $\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k,t \in s\right)$ is a continuous and increasing function of a, with value 1 for a=1 and value less than or equal to ½ for *a=1/2.* We then apply proposition 2, concluding the proof of corollary 2.

II.3. The extended game

In this section, we will introduce two more actions to the ruler’s set of strategies. The first one gives the government an opportunity to “shape” the network before making the allocation, eliminating a subset of nodes and its respective links. This option is called “repression”. The second one gives the ruler has the possibility to change the priorities of citizens, which will be noted as “propaganda”.

Specifically, with the original network (Γ, N), the ruler could choose a set $R \subset N$ of citizens such that the agents in $N-R$ will be eliminated or insolated, so that they would no longer be in the network, nor would they receive any endowment (i.e. $X_i = 0, \forall i \in N-R$). Then, the network after repression is: (Λ, R) instead of (Γ, N), where $\Lambda = \{ij / ij \in \Gamma, i \in R, j \in R\}$.

However, it is realistic to assume that there is a government cost when repressing citizens. We can assume that each “eliminated” node produces a loss for the ruler equivalent to j units of consumption good. Thus, moving from the original network (Γ, N) to (Λ, R) will cost the ruler $\#(N-R)j$ units of consumption good.

After "shaping" the network, the government has another option: changing the citizens' priors using propaganda. We formalize this argument by assuming a discrete "propaganda function" $\{r_k, G_k\}_{k=0}^{K}$, where $L_k > L_{k-1} \geq 1, k = 1,...,K$ and $G_k > G_{k-1} \geq 0, k = 1,...,K$. r_k represents the ratio among priors of citizens. So, $r_k = \dfrac{P_i(X_j = H)}{P_i(X_j = L)}, \forall j \in R, j \neq i, \forall i \in R$ after the ruler expends G_k in advertising.

Hence, the new strategy set of the ruler will be:

$$S_0 = \{\{R, R \subset N\}, \{G_k, k = 0,...,K\}, \{\{X_i\}_{i \in R}, X_i \in Q\}\}$$

The ruler's payoff will be $U\left(T - \sum_{i \in R} X_i - G_k - j\,\#(N - R)\right)$ if not defeated, and 0 if defeated.

After the government has decided the set *N*-*R* of nodes to be eliminated, the propaganda level k, and the endowments $\{X_i\}_{i \in R}$, it is time for the citizens in R to move[17]. The strategies and payoffs of citizens are the same as before. Also, in order to decide which action to take, the agents in R will still actualize its priors r_k using signals $\{\hat{X}_{ji}\}_{i,j \in R}$ in the same manner as explained in Chapter II.2.

Hence, the ruler's problem becomes:

$$P.2 \quad \begin{array}{c} Max \\ R, k, \{X_i\}_{i \in R} \end{array} \quad \begin{array}{l} \left[1 - \hat{P}\left(\Phi; a, (\Lambda, R'), \{X_i\}_{i \in R}\right)\right] U\left(T - \sum_{i \in R'} X_i - G_k - j\,\#(N - R)\right) \\ s.t \quad R \subset N, 0 \leq k \leq K, X_i \in Q \quad i \in R \end{array}$$

Thus, we can restate Proposition 1 in the following way:

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[17] Citizens in N-R, of course, will not have any chance to move.

Proposition 1'. If for some $s \subset N'$ with $\hat{f}$ members, where $X_i = L$ for $i \in s$, it is true that $\frac{\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k, t \in s\right)}{\prod_{\substack{k \in s \\ k \neq i}} \left[a_{11}(d(ki)) + r_k a_{11}(d(ki))\right]} \geq p$, for some $p \geq \frac{U(L)}{U(M)}$ then "attack" will be played with probability 1 for agents in s in event $E = \{w \in \Omega / \hat{X}_{ik} = L; k, i \in s\}$.

The proof of the proposition is in Appendix 3.

Note that the expression $\frac{\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k, t \in s\right)}{\prod_{\substack{k \in s \\ k \neq i}} \left[a_{11}(d(ki)) + r_k a_{11}(d(ki))\right]} \geq p$ decreases as L_h increases. This means that any revolt can be precluded if r_k is high enough to ensure the inequality:

$$\frac{\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k, t \in s\right)}{\prod_{\substack{k \in s \\ k \neq i}} \left[a_{11}(d(ki)) + r_k a_{11}(d(ki))\right]} < \frac{U(L)}{U(M)}.$$

III. EXAMPLES

III.1. Example 1

Let us analyze the simplest network: two agents connected by one link. The number of agents needed to defeat the ruler is, of course, two. Hence, the set of strategies for agent zero is the set of endowments:

$$S_0 = \{\{X_1 = H, X_2 = H\}, \{X_1 = L, X_2 = H\}, \{X_1 = H, X_2 = L\}; \{X_1 = L, X_2 = L\}\}$$

Therefore, the obstacle for the ruler is to decide whether to assign L to only one agent or to both. If only one agent receives L, the utility of the ruler is $U(H - L)$. We can find cases when the ruler obtains a higher expected utility by assigning L to both agents. Assuming that he does this, we have:

The probability $\hat{P}\left(\{\hat{X}_{12}, \hat{X}_{21}\}, a, (\Gamma, N), \{X_1, X_2\}\right)$ is:

$$\hat{P}\left(\hat{X}_{12} = H, \hat{X}_{21} = H\right) = (1-a)^2 \leq 1/4$$

$$\hat{P}\left(\hat{X}_{12} = H, \hat{X}_{21} = L\right) = (1-a)a$$

$$\hat{P}\left(\hat{X}_{12} = L, \hat{X}_{21} = H\right) = (1-a)a$$

$$\hat{P}\left(\hat{X}_{12} = L, \hat{X}_{21} = L\right) = a^2 \geq 1/4$$

Event $E = \{\hat{X}_{12} = L, \hat{X}_{21} = L\}$ is p-evident for $s = \{1,2\}$ and for some p between 0 and 1, if and only if: $P\left(\hat{X}_{12} = \hat{X}_{21} = L \mid X_1 = X_2 = L\right) \geq p$, that is, if $a^2 \geq p$. However, if $a^2 < \frac{U(L)}{U(M)}$, then the strategy “attack” will never be a p-dominant strategy for any agent. In this case, the ruler could assign a lower endowment to both agents and not fear a revolt.

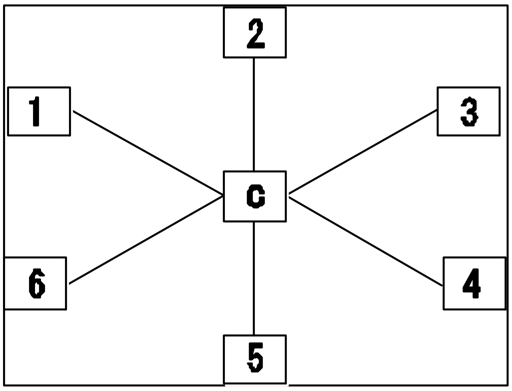
On the other hand, if $a^2 \geq \frac{U(L)}{U(M)}$, then when event $E = \{\hat{X}_{12} = L, \hat{X}_{21} = L\}$, the strategy "attack" for both agents will be a p-dominant equilibrium played with probability 1 on such event. Agent zero will take the risk if:

$$\{1 - \hat{P}[E;(\Gamma, N), a, \{X_1 = X_2 = L\}]\}U(3H - 2L)) = (1 - a^2)U(3H - 2L) \geq U(2H - L)$$

An extreme example of a ruler willing to bear such a risk is, of course, a risk neutral ruler, in which the inequality will become: $(1 - a^2)(3H - 2L) \geq 2H - L$. Recalling $a^2 \geq 1/2$, we obtain: 2>3, which means that agent zero will never take such a risk. Hence, any ruler will assign L to both agents if and only if $a^2 < \frac{U(L)}{U(M)}$. Otherwise, he will assign L to one agent and H to the other.

III.2. Example 2

We have a more interesting example when there is a network:



In this network the salient feature is the central agent c, who has contact with every agent in N. The remaining agents, we can call them the periphery agents, have to rely on the information they receive through c. There are several possible distributions. The following are the most important ones.

Assume $\hat{f}$ =3 and each agent in $F \subset N$ $(\#(F) \geq 3$ and c is in F) is assigned L. Let $s \subset F$ be a group with three elements, again including c, whose agents receive a signal $E = \left\{ \hat{X}_{st} = L; s,t \in s \right\}$. "Attack" will be a p-dominant equilibrium played with probability 1 on this event if the following condition holds:

$$\hat{P}\left(\hat{X}_{ij} = L \mid X_i = L; i,j \in s\right) \geq p \geq \frac{U(L)}{U(M)}$$

This means that in this context $a^6 \geq p \geq \frac{U(L)}{U(M)}$. If this is true, the probability that the ruler would be defeated is high, because it is highly probable that at least 3 agents whose endowment is L receive signal E.

Another distribution that may improve the ruler's expected utility is to give H to c and L to everybody else. This means that the endowment of the agent will depend on his position in the network: the well-connected receive higher endowments. That is what we call "cooptation". Consider a group $\tilde{s} \subset F$ of 3 elements. "Attack" will be played with probability 1 in the event $E = \left\{ \hat{X}_{st} = L; s,t \in \tilde{s} \right\}$ if this condition holds:

$$\hat{P}\left(\hat{X}_{ij} = L \mid X_i = L; i,j \in \tilde{s}\right) \geq p \geq \frac{U(L)}{U(M)}.$$

However, since signals $\hat{X}_{ij} = L$ are coming from the periphery, this probability is:

$$\hat{P}\left(\hat{X}_{ij} = L \mid X_i = L; i,j \in s\right) = \left(a^3 + (1-a)^3\right)^3 .$$

Additionally, whenever $a>1/2$ we have $\left(a^3 + (1-a)^3\right)^3 < a^6$. Thus, it is possible that we have $a^6 \geq p \geq \frac{U(L)}{U(M)} > \left(a^3 + (1-a)^3\right)^3$, which means that it would be easier to develop coalitions when c receives L, but impossible if agents in the periphery only have prospective allies from the periphery. In such case, the ruler can safely assign L to everybody with agent c receiving H.

We could also note that, given the inequality $a^6 \geq p \geq \frac{U(L)}{U(M)} > \left(a^3 + (1-a)^3\right)^3$, if the network is fully connected (i.e. the degree of separation between any two agent is 1), the extraction level cannot be greater than 2.

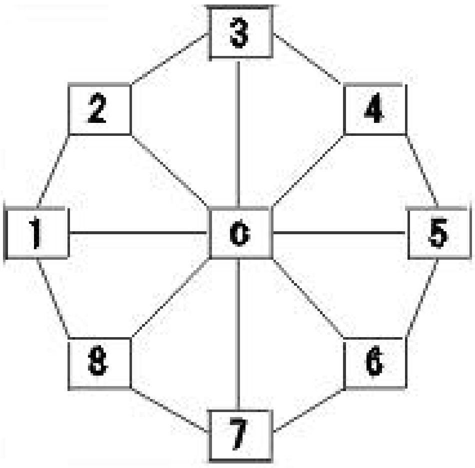
III.3. Example 3

Now consider the parameters stated in table 1 and the network that appears in graph xx.

Table 1

A	0.989	**n**	9
T	10	**initial priors**	0.95
M	1	**cost of repression**	0.6
$\hat{M}$	0.95	**change in priors**	0.4
z	0.65	$\hat{f}$	4

We assume that the initial priors ratio is 0.95 and for every "unit of propaganda", the priors ratio would increase in 0.4 points. We would consider different cost of the unit



Graph 1

of propaganda. To “eliminate” one citizen costs 0.6, but to reduce the number of options the ruler has, we assume that no more than two agents could suffer a repression[18].

Although the government has several strategies[19] to choose from, there are fewer pertinent options because it is not relevant to identify agents, but their relative position in the network[20]. Furthermore, many options can be eliminated following ideas developed previously and adding a few assumptions, such as the following.

First, we know that a coalition of four is enough to defeat the ruler, so it will be useful when analyzing a ruler’s strategy to identify the group of four citizens that are most probable in forming a successful coalition (noted as $\hat{s}$). If we look for a crowd of agents with the closest proximity, this group will be easy to identify. It is useful to focus our attention on this group because, if the network structure and noise level are such that E cannot be common p-believed by $\hat{s}$ for a p high enough, obviously this will be the case for any other possible coalition. On the other hand, if it happens that E can be common p-believed by $\hat{s}$ for a p high enough, the probability:

$$P\left\{ w \in \Omega / \left\{ \hat{X}_{ij} = L \right\}, j \in \hat{s}, i \in \hat{s}, \hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; t,k \in \hat{s} \right) \geq \frac{U(L)}{U(M)} \right\}$$

will be at a lower bond for $P(\Phi)$, which will be useful later on.

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[18] After all, the elimination of 3 citizens means 33% of the population suffers repression, which is too much under any consideration.

[19] Recall that a ruler’s strategy consists of an allocation, a set of citizens to be eliminated and a propaganda level.

[20] For example, two allocations $\{Y_i\}$ and $\{Z_i\}$ such that $Y_i = Y_i = L$ for $i = 3,..9$ and $Y_1 = Z_2 = H$ and $Y_2 = Z_1 = L$ are the same for this analysis, because the probability of a revolt and his expected utility are independent of the identity of the agents.

Note that, since $\hat{f} = 4$, the ruler can safely assign L to three agents, being indifferent to the position of such agents in the network. Hence, the minimum utility the ruler could get in this game is $U(T - 5M - 3Z)$.

We can, then, simplify the problem to ensure that the ruler does not risk the possibility of a revolt (i.e. the allocation will be such that Φ is an empty set). This will be the case if for every possible strategy $\left\{\{X_i\}_{i=1}^{9}, k, R\right\}$ with $P(\Phi) > 0$:

$$[1 - P(\Phi)]U\left(T - \sum_i X_i - G_k - j\,\#(N - R)\right) < U(T - 6H - 3L)$$

meaning that it will be better if the ruler uses the "safe" allocation instead of risking a revolt. In general, we can ensure that this occurs for a risk neutral ruler if, using some algebra and applying the lower bound for $P(\Phi)$, we set the final assumption as:

$$P\left(\hat{X}_{ij} = L \mid \hat{X}_i = L; i, j \in \hat{s}\right) > \frac{6H + 3L - \sum_i X_i}{T - \sum_i X_i}$$

As we said, there is a minimum utility for the ruler where he can safely allocate L to three agents. Then, an alternative allocation should be considered only if there are networks of at least four citizens receiving L. Maximizing the distance between the potential rebels is the safest method to do it[21]:

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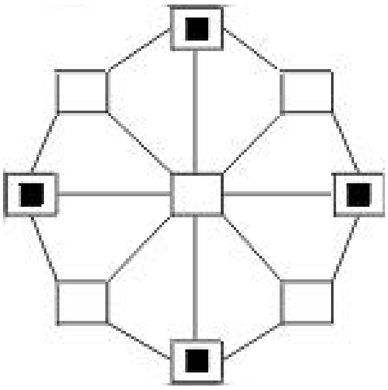
[21] We note a citizen receiving H as an empty square and a citizen receiving L as a square with a box inside.

Strategy 1:



Now the question is: For what value of p can E be common p-believed in this case? We already know E depends on the value:

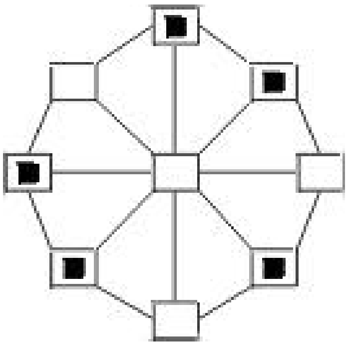
$$\Psi = \frac{\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k,t \in s\right)}{\prod_{\substack{k\in s\\ k\neq i}} \left[a_{11}\left(d(ki)\right) + r_k a_{11}\left(d(ki)\right)\right]}$$

which for this case is[22]:

$$\Psi = \frac{[a_2]^{12}}{[a_2 + r_h(1-a_2)]^3}$$

In the same way, we can analyze the other options of the ruler:

Strategy 2:



$$\Psi = \frac{\left[a(a_2)^2\right]^4}{[a + r_h(1-a)][a_2 + r_h(1-a_2)]^2}$$

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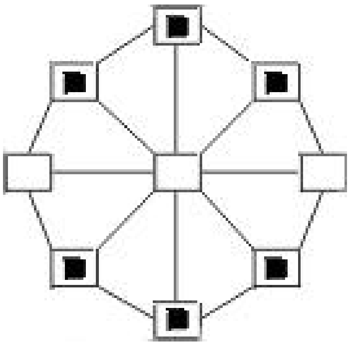
[22] We will use the notation $a_2 = a_{11}(2) = a^2 + (1-a)^2$, $a_3 = a_{11}(3) = aa_2 + (1-a)(1-a_2)$, and $a_4 = a_{11}(4) = aa_3 + (1-a)(1-a_3)$

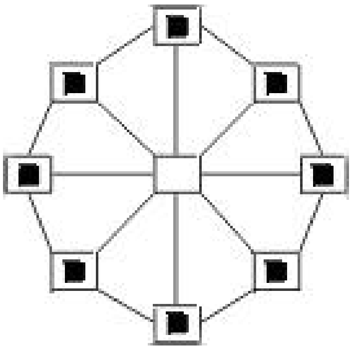
Strategy 3:



$$\Psi = \frac{a^{4}(a_{2})^{8}}{\left[a_{2} + r_{h}(1-a_{2})\right]^{3}}$$

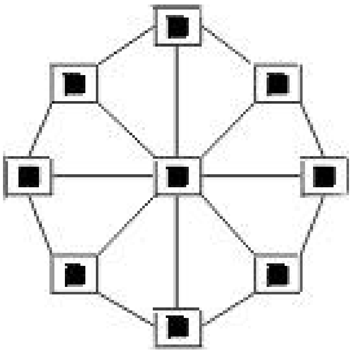
The preceding strategies are the best options to allocate *L* to four, five and six citizens. Consider a strategy with seven agents receiving *L*, which always have four agents in a row. If the ruler makes such allocations, then it is impossible for a revolt by these agents and impossible for a coalition to form any group of four in a row. Thus, the government can assign *L* to every citizen except the central citizen.

Strategy 4:



$$\Psi = \frac{a^{6}(a_{2})^{6}}{\left[a + r_{k}(1-a)\right]\left[a_{2} + r_{k}(1-a_{2})\right]^{2}}$$

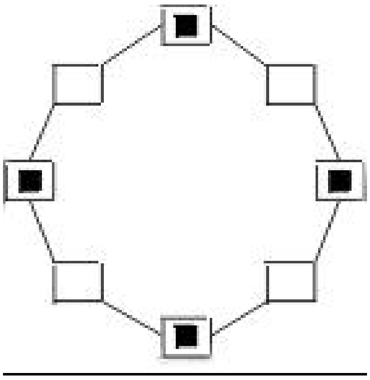
Strategy 5:



$$\Psi = \frac{a^{10}(a_{2})^{2}}{\left[a + r_{k}(1-a)\right]^{2}\left[a_{2} + r_{k}(1-a_{2})\right]}$$

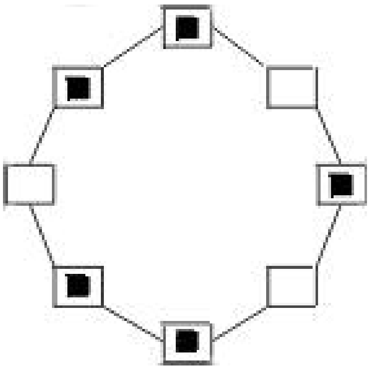
In the following strategies, we will add repression to the ruler’s option. Obviously, if anyone should be eliminated that would be the central agent.

Strategy 6 :



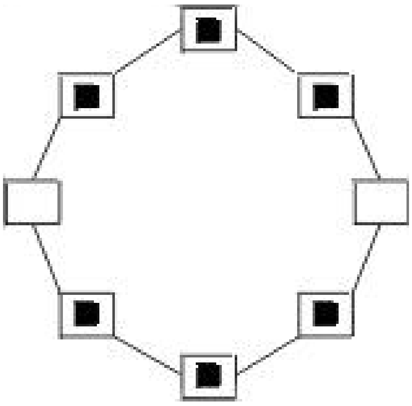
$$\Psi = \frac{(a_2)^8 (a_4)^4}{[a_4 + r_k(1-a_4)][a_2 + r_k(1-a_2)]^2}$$

Strategy 7 :



$$\Psi = \frac{a^4 (a_2)^2 (a_3)^4 (a_4)^2}{[a + r_k(1-a)][a_2 + r_k(1-a_2)][a_4 + r_k(1-a_4)]}$$

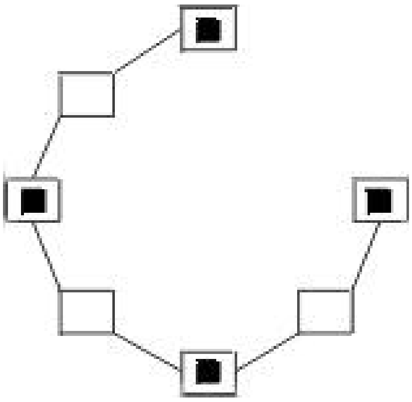
Strategy 8 :



$$\Psi = \frac{a^4 (a_2)^4 (a_3)^2 (a_4)^2}{[a_2 + r_k(1-a_2)][a_3 + r_k(1-a_3)][a_4 + r_k(1-a_4)]}$$

Next, a strategy with two citizens eliminated.

Strategy 9:



$$\Psi = \frac{a^6 (a_2)^4 (a_3)^2}{\left[a + r_k (1-a)\right]\left[a_2 + r_k (1-a_2)\right]\left[a_3 + r_k (1-a_3)\right]}$$

Each strategy can be evaluated numerically using parameters from Table 1. The results are as follows. When the propaganda cost is 0.1, the best strategy for the ruler is Strategy 5: no repression (R=N), propaganda level 6, and every citizen receiving *L*. On the other hand, if the propaganda cost is 0.3 the best strategy will be Strategy 4: no repression, propaganda level 3, and eight agents receiving *L*. In this case only the central agents gets H, which again is an example of cooptation. Finally, Strategy 8 will be the best for the government if the propaganda cost is 0.6. In this case, no propaganda is necessary with six agents receiving *L* and two receiving *H*, where the central agent is eliminated. As we can see, whether the central agent receives a higher income or is eliminated depends on the relative prices of elimination, propaganda and the endowments levels.

IV. DISCUSSION

VI.1. Ethnic fractionalization and rent-seeking governments

Poor economic performance of almost all sub-Saharan countries has been of concern to economists for decades (see, for example, Collier and Gunning 1999, and included references). Easterly and Levine (1997) argued that ethnic conflict, which has troubled these countries, especially since their independence from European powers, is a major explanation of such low performance. Alesina et al (2002) confirm a strong link between ethnic and linguistic fractionalization on one hand, and poor quality of institutionalization and low growth on the other.

Although such studies shed considerable light on the issue, it is difficult to accept a general one-dimensional, unidirectional, and monotonic relationship between ethno-linguistic fractionalization and economic performance (see Esman and Herring 2002), especially since they are based on cross-sectional analysis. Instead, case studies can help us better understand the relationships between these variables. In this section, we apply our model of distribution and noise communication in networks in the Nigeria and Congo/Zaire cases.

First, we have to take into account that the main income of these countries comes not from production but from rents. This is essential because these countries have rich subsoil, but a poor entrepreneurial environment. Nigeria has oil, producing $280 billon in revenues since its discovery of reserves in the late 1950s (Alesina et al). Meanwhile, Congo is rich in minerals such as cobalt, copper, and diamonds, where the exportation constitutes the majority of the national taxable income. Hence, we can think of these economies as “distributive” rather than “productive” and we could apply our model to them.

Next, note that both countries, according to Alesina et al’s index,[23] are among the most ethnically and linguistically diverse in the world. Congo has an ethnic fractionalization index of 0.874 while Nigeria’s is 0.85. Germany, by comparison, has 0.16. The majority of the Nigerian population is distributed in 350 ethnic groups that are excluded from political power.[24] Therefore, we could use our model to represent each ethnic group as a node in the network. The linkages are defined by communication channels connecting these groups, which are subject to cultural and linguistic restrictions (i.e. it is not the case that everyone is connected to everyone else). Also, it has been documented (Alesina and La Ferrara, 2002) that the trust level is low among people of diverse racial backgrounds. This lack of trust introduces noise in the communication between the nodes of our network.

In this scenario, our model predicts that an elite or a dictator will take advantage of the lack of linkage among the nodes (ethnic groups) and of the noise present in the communication links between the nodes, in order to appropriate a significant share of the country’s wealth. Also, we can see that the ruler prevents the development of communication channels, breaking them up whenever possible and increasing the distrust (noise) among the nodes as much as he can. In the case of Congo and its dictator/president from 1965 to 1997, Castells (2000, p.100) states: “Mobutu relied on a very simple system of power. He controlled the only operational unit of the army, the presidential guard, and

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[23] This index measures the probability that two persons of that country, chosen randomly, happen to belong to different ethnic groups.

[24] Unless explicitly stated, the data and facts about African countries, specifically Nigeria and Congo, are from Castells (2000).

divided politics, government, and army positions among different ethnic groups. He patronized all of them, but also encouraged their violent confrontation." With respect to wealth appropriation by the ruler, note that Mobutu had in 1993 a personal fortune of $10 billon outside his country. Generally, in sub-Saharan states there are few wealthy individuals. These few individuals display high levels of consumption while exporting capital to personal accounts in Europe and the U.S. This wealth represents a significant proportion of each country's capital. Meanwhile, most of the population survives under chronic conditions of poverty.

So, according to our analysis, the ruler in each of these countries has chosen an appropriation/distribution strategy, instead of a production/taxation one. This will have an additional effect: The regime does not care in providing a safe environment for business, enforcing property rights and contracts, or providing other public goods, since taxation is not the source of his income. The evidence in Nigeria and Congo could not be any clearer.

IV.2. Common Knowledge and collective action in noisy networks

In this model, the lack of common knowledge in the distribution of wealth makes it possible for the ruler to increase his expected utility, making "unfair" and uneven allocations of available income[25]. The specific extraction level the regime could exercise depends on the entire structure of the network and on the channel capacity. In that sense, these two factors define political equilibrium between the government and its citizens.[26] We can say, then, that a well-connected network with good communications channels

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[25] As stated in the introduction, this model approaches the case of a dictatorial ruler, since no electoral process is considered.

[26] Those are the only determinants of the extraction power, since the incentive-distorting effect analyzed by Olson (1996) and Acemoglu (2002) is not considered in this model. Also, note that the lack of collective action against the ruler will be due only to the lack of common knowledge, since the free rider effect is not present in this model.

serve as a counterbalance to government power, precluding abusive behavior on the part of the ruler. Also, they facilitate a more equalitarian distribution of wealth by making excessive or non-justified extractions more difficult to achieve.[27]

In that sense, this model helps us understand why regimes (or rulers in the broader sense) have been cautious of networks that facilitate communication among its citizens or subordinates. For example, Chwe (2002) reports that Hawaiian farmers hired workers who did not all speak the same language. Tilly (1997), discussed the Tudors' effort to build a centralized English state, saying that they discouraged the cooperation of their dependents and tenants. In the worst moments of some Latin-American dictatorships, people were not allowed to join groups over a limited number of persons. Communist regimes took care to systematically preclude their citizens from gaining free access to communication devices such as radio transmitters, photocopiers, etc. This was also the case with the European colonialization method in Africa, where "on the one hand there was the legal state, as a racialized entity, under the control of the Europeans; on the other hand was the customary power of native power structures, as an ethnic/tribal identity. The unity of the former and the fragmentation of the latter were essential mechanisms of control under colonial administrations…." (Castells, 2000, p 106).

Networks have been studied in several sciences. Strogatz (2001) and Newman (2002) explain that networks (from neural networks to food webs to semantic linkages) present several statistical similarities, among them "skewed degree distributions." The

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[27] An anecdote from Chwe (2001) serves to illustrate how our model works. Chwe relates that in 1977, the Egyptian government announced an increase in the price of bread after 30 years of a frozen price, which provoked major riots and protests against the government. Eventually, the announced increment was rescinded, but loaves of bread were made smaller and were of lower quality. Although everybody noticed the change, it was not common knowledge since the government did not announce it. There were no disturbances.

degree of a node is the number of other nodes to which it is connected. Usually, there is a small positive number of nodes that exhibit very high degrees.

The knowledge about networks can be useful in understanding political and economic issues using models such as the present one. For example, Barabasy (2002) explains how a network is immune to a relatively short number of random attacks. Because the degree distribution is skewed, the attacks directed against hubs could seriously affect network connectivity. In our model, this is not difficult to analyze if we give the ruler the opportunity to "shape" the network before the citizens' move begins. A repressive regime could then try to eliminate people who are highly connected and, thus, by reducing network connectivity, it could increase its expected utility. There is, however, an alternative to treating the well-connected: cooptation, that is, to pay them a higher income. However, whether is better to eliminate or to co-opt a well connected agent is question of relative cost.

Another implication of this model is the emergence of economic inequality, not only between the ruler and the citizens, but also among the citizens, since the well connected are more likely to receive a bigger allocation.

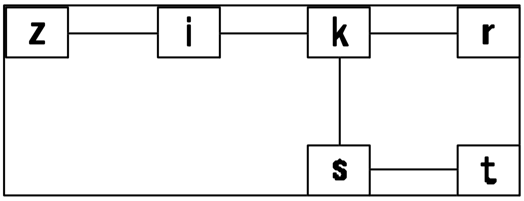
"The best common knowledge generator in the U.S. today is network television," says Chwe (1998) in analyzing the role of the media in collective action. In fact, when a citizen learns news from TV, he not only knows it, but also knows it is common knowledge for a great number of people watching the same show. In our model, free media reporting on the distribution of wealth will make the emergence of a successful rent-seeking regime impossible. However, if the government controls the media, citizens have to rely on their own network to learn about the others' situations, which makes wealth extraction possible.

There is an emerging body of literature on the relationship between media and government (Besley and Prat, 2001, Djankov, S. et al, 2002). Although much of this work applies to electoral systems, the implications of our model are somewhat consistent with their results, showing that government ownership of media undermines political and economic freedom.

APPENDIX 1

HOW TO CALCULATE $P\left(\left\{\hat{X}_{ij}\right\}_{i=1..n}^{j=1..n}\right)$

First note that $P\left(\left\{\hat{X}_{ij}\right\}_{i=1..n}^{j=1..n}\right)=\prod_{j=1}^{n}P\left(\left\{\hat{X}_{ij}\right\}_{i=1..n}\right)$, since the signal agents *1,2,.., s -1, s +1,.., n* receive about X_s are independent to the signal agents *1,2,.., j -1, j +1,.., n* receive about $X_j, s \neq j$. Looking at $P\left(\left\{\hat{X}_{ij}\right\}_{i=1..n}\right)$, it is clear that there could be a stochastic dependence among these signals, depending on (Γ, N), thus, depending on the pathway the signals have traveled. Take for example the following network:



The probability of this realization of signals comes from j [28]: $\left\{\hat{X}_{zj}, \hat{X}_{kj}, \hat{X}_{sj}, \hat{X}_{rj}, \hat{X}_{tj}\right\}$ given $X_j = q_l$,is:

$$P\left(\hat{X}_{zj}, \hat{X}_{kj}, \hat{X}_{sj}, \hat{X}_{rj}, \hat{X}_{tj} \mid X_j\right)= P\left(\hat{X}_{zj} \mid X_j\right)P\left(\hat{X}_{kj}, \hat{X}_{rj} \mid X_j\right)P\left(\hat{X}_{sj}, \hat{X}_{tj} \mid \hat{X}_{kj}\right)=$$

$$P\left(\hat{X}_{zj} \mid X_j\right)P\left(\hat{X}_{kj} \mid X_j\right)P\left(\hat{X}_{rj} \mid \hat{X}_{kj}\right)P\left(\hat{X}_{sj} \mid \hat{X}_{kj}\right)P\left(\hat{X}_{tj} \mid \hat{X}_{sj}\right)=P_{zj,j}^{(1)}P_{kj,j}^{(1)}P_{rj,kj}^{(1)}P_{sj,kj}^{(1)}P_{tj,sj}^{(1)}$$

Generalizing, we could classify the agents depending on its position with respect to j:

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[28] We are noting the event $\left\{\hat{X}_{zj} = q_{zj}, \hat{X}_{kj} = q_{kj}, \hat{X}_{sj} = q_{sj}, \hat{X}_{rj} = q_{rj}, \hat{X}_{tj} = q_{tj}\right\}$ where $q_{ab} \in \{q_1, q_2\}$ is $\left\{\hat{X}_{zj}, \hat{X}_{kj}, \hat{X}_{sj}, \hat{X}_{rj}, \hat{X}_{tj}\right\}$.

A_1 = the set of “terminal” agents. From these agents no player receives information about X_j.

$$A_2 = \left\{ s \in N / \exists k \in A_1 : k \; gets \quad \hat{X}_{kj} \; from \quad s \right\}$$

:

:

$$A_m = \left\{ s \in N / \exists k \in A_{m-1} : k \; gets \quad \hat{X}_{kj} \; from \quad s \right\}$$

We can see that $m < n$ and $\{A_l, l = 1,2,..n\}$ is a partition of $N \setminus \{j\}$. Note the geodesic going from i to j:

$$G_{ij} = \{k_1 k_2, k_2 k_3, .., k_{h+1} k_h : k_l k_{l+1} \in \Gamma; l = 1,.., h; k_1 = i; k_m = j\}$$

And:

$$G_j = \bigcup_{i=1}^{n} G_{ij}$$

Hence, G_i is the collection of all links that correspond to the geodesics going from j to every other agent in N. Using this notation and keeping in mind that signals travel across the networ k as Markov chains, we can write:

$$P\left(\left\{\hat{X}_{ij}\right\}_{i=1..n}\right) = \prod_{l-1}^{m} \prod_{a(l) \in A_i} P\left(\hat{X}_{a(l)j} \mid \hat{X}_{bj}, b \in A_{l+1}\right) = \prod_{l-1}^{m} \prod_{a(l) \in A_i} P\left(\hat{X}_{a(l)j} \mid \hat{X}_{bj}, b \in A_{l+1}, a(l)b \in G_i\right)$$

We note that $\{\hat{X}_{bj} = X_j, b \in A_{m+1}\}$ for $\{\hat{X}_{bj}, b \in A_{m+1}\}$, completing the explicit definition of *P(.)*.

APPENDIX 2

Lemma 1. The necessary and sufficient condition for $E = \{w \in \Omega / \hat{X}_{ik} = L; k, i \in s\}$ common *p*-believed in E (i.e. $C^p(E) = E$) is $\hat{P}(\hat{X}_{tk} = L \mid X_k = L; k, t \in s) \geq p$.

The first step is to find $B_i^p(E)$ for any $i \in s$, using $B_i^p(E) = \{w \in \Omega / P_i(E \mid \Psi_i(w)) \geq p\}$. The only candidates that can be elements of $B_i^p(E)$ are ω such that $\Psi_i(w) = \{w \in \Omega / \hat{X}_{ik} = L, \forall k \in s\}$. Because the probability i assigned to E only depends on the information i receives, we only have two possibilities: $B_i^p(E) = \Psi_i(w)$ or $B_i^p(E) = f$. This is true because any two element in an i partition yields the same signals to i. Hence we can say:

$$B_i^p(E) = \{w \in \Omega / \hat{X}_{ik} = L; k \in s\} \Leftrightarrow P_i(X_k = L, \hat{X}_{tk} = L \mid \hat{X}_{ik} = L; k, t \in s, i \neq t) \geq p$$

$$\text{and } B_i^p(E) = f \Leftrightarrow P_i(X_k = L, \hat{X}_{tk} = L \mid \hat{X}_{ik} = L; k, t \in s, i \neq t) < p$$

Next, we calculate the conditional probability on the left side of this bi-conditional statement. Again, it will depend on the network structure and noise level:

$$P_i(X_k = L, \hat{X}_{tk} = L \mid \hat{X}_{ik} = L; k, t \in s, t \neq i) = \frac{P_i(X_k = L, \hat{X}_{tk} = L; k, t \in s)}{P_i(\hat{X}_{ik} = L; k \in s)}$$

The expression in the denominator is not difficult to calculate: given our Laplacian priors and the stochastic independence of the signals originated in different agents, the probability that agent i receives *f-1* signals L is $(1/2)^{f-1}$. The numerator is calculated as follows:

$$P_i(X_k = L, \hat{X}_{tk} = L; k, t \in s) = \hat{P}(\hat{X}_{tk} = L \mid X_k = L; k, t \in s) P_i(X_k = L; k \in s, k \neq i)$$

Again, the priors we have assumed tell us: $P_i\left(X_k = L; k \in s, k \neq i\right) = (1/2)^{f-1}$. On the other hand, $\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k, t \in s\right)$,which is the probability everyone in s receives and L from everyone in s, given that everyone in s has an endowment of Z- depending on the network structure (Γ, N) and on the noise level $1-a$. We have dropped the sub index in that expression, because it is equal to every agent in s [29], and added a hat to P because it is the same probability distribution we had explained in Appendix 1. The precise way to calculate such value could also be seen in the preceding examples. For now, we can write:

$$P_i\left(X_k = L, \hat{X}_{tk} = L \mid \hat{X}_{ik} = L; k, t \in s, t \neq i\right) = \hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k, t \in s\right)$$

Thus, if and only if the condition $\hat{P}\left(\hat{X}_{tk} = Z \mid X_k = Z; k, t \in s\right) \geq p$ holds, we can say $B_i^p(E) = \Psi_i(E) = \left\{w \in \Omega / \hat{X}_{ik} = L; k \in s\right\}$. The reasoning is the same for all agents in s, hence it is the necessary and sufficient condition to say

$$B^p(E) = \bigcap_{i \in s} B_i^p(E) = \bigcap_{i \in s} \Psi_i(w) = \left\{w \in \Omega / \hat{X}_{ik} = L; k, i \in s\right\} = E$$

and following to higher order beliefs:

$$B^p \ldots B^p(E) = \left\{w \in \Omega / \hat{X}_{ik} = L; k, i \in s\right\} = E$$

This completes the proof.

---

[29] Note that every agent is receiving only "L " as signals from s .

APPENDIX 3

We will explain the difference between proposition 1 and proposition 1’, which is the inequality:

$$\frac{\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k,t \in s\right)}{\prod_{\substack{k\in s\\ k\neq i}}\left[a_{11}(d(ki)) + r_k a_{11}(d(ki))\right]} \geq p$$

This inequality comes from the condition for E to be common p-believed in E by following the proof of Lemma 1:

$$P_i\left(X_k = L, \hat{X}_{tk} = L \mid \hat{X}_{ik} = L; k,t \in s, t \neq i\right) = \frac{P_i\left(X_k = L, \hat{X}_{tk} = L; k,t \in s\right)}{P_i\left(\hat{X}_{ik} = L; k \in s\right)} \geq p$$

However, we need to take into account when the priors ratio does not equal 1. The denominator would be:

$$\begin{aligned} P_i\left(\hat{X}_{ik} = L; k \in s\right) &= \prod_{\substack{k\in s\\ k\neq i}} P_i\left\{\hat{X}_{ik} = L\right\} \\ &= \prod_{\substack{k\in s\\ k\neq i}} \left\{P_i\left\{\hat{X}_{ik} = L \mid X_k = L\right\} P_i\left\{X_k = L\right\} + P_i\left\{\hat{X}_{ik} = L \mid X_k = H\right\} P_i\left\{X_k = H\right\}\right\} \\ &= \prod_{\substack{k\in s\\ k\neq i}} \left\{P_i\left\{\hat{X}_{ik} = L \mid X_k = L\right\} + L_h P_i\left\{\hat{X}_{ik} = L \mid X_k = H\right\}\right\} P_i\left\{X_k = H\right\} \end{aligned}$$

Meanwhile the numerator is:

$$P_i\left(X_k = L, \hat{X}_{tk} = L; k,t \in s\right) = P\left\{\hat{X}_{tk} = L \mid X_k = L; t,k \in s\right\} \prod_{\substack{k\in s\\ k\neq i}} P_i\left\{X_k = L\right\}$$

Finally, we obtain:

$$\frac{\hat{P}\left(\hat{X}_{tk} = L \mid X_k = L; k,t \in s\right)}{\prod_{\substack{k\in s\\ k\neq i}}\left(a_{11}^{d_{ki}} + r_h a_{11}^{d_{ki}}\right)} \geq p$$

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(lix) This paper was presented at the ENGIME Workshop on “Mapping Diversity”, Leuven, May 16-17, 2002

(lx) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002

(lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003

(lxii) This paper was presented at the ENGIME Workshop on “Communication across Cultures in Multicultural Cities”, The Hague, November 7-8, 2002

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(lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003

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(lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003

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