TOLLING THE RHINE in 1254: COMPLEMENTARY MONOPOLY REVISITED*

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1. Introduction: the Rhine League

Every year, millions of tourists, *Colour Photoguide* in hand, embark on a Rhine cruise. These tourists are touring not just picturesque historical landmarks but also the scene of interesting Nash equilibria. The castles and ruins mark the sites of former tolling stations along the Rhine River valley. History records that at one time or another during the millennium 800-1800, 79 different locations served as toll booths along the Rhine and its tributaries [Pfeiffer, preface pp. v-vii]. The Rhine River was the major commercial thoroughfare in Western Europe during this time, and Rhine customs and tolls were a major source of revenue for the Holy Roman Empire. As such, the Emperors closely guarded the right to collect tolls. Such a right could be granted only by the Emperor. For instance, one well-documented tolling station that operated continuously throughout the Middle Ages, Koblenz, first got this right in 1018 [Pfeiffer, p. 83]. Formally, the right to collect a toll had to be renewed with each new Emperor, and renewal was not automatic.

Given a demand for Rhine travel, an Emperor faced a classic complementary monopoly problem: how many toll stations to have, where to site them, and what toll to charge at each. As a basic part of the answer to this problem, Emperors tended to keep the number of stations low. For instance, in 1250–an important date in our analysis--there were 12 stations on the Rhine between Mainz and Cologne [Pfeiffer, p.332] . Siting was a complicated decision, whose components included the local power structure (powerful ecclesiastical or noble interests were likely recipients), spacing (a 5 kilometer minimum seems to have been observed), and defensibility (some of the castles which acted as toll booths survived as military structures until the French invasion of 1689).

The standard toll for an average ship in 1241 was 8 denari (1 denarus equaled 0.68 grams of silver). Larger ships paid a larger toll [Pfeiffer, p. 100]. There are also records of in-kind tolls being collected, mainly in specific cargoes (lead, copper, wine, slaves) and mostly in the Lower Rhine Valley (today's Netherlands) [Pfeiffer, 117-127]. In-kind tolls tended to be much heavier than their monetary counterpart.[1]

Thus, the system of tolls along the Rhine in 1250 was not unlike those of today, where governments typically charge tolls at established toll booths at various conveniently spaced locations. At that time, the castles were established like businesses selling rights of passage.[2]

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[1] Physical characteristics of the river also played a role in siting. As *Colourphoto Guide* reports (p.3), at Mainz, the River is 520 meters wide, while from Bingen onwards, it is a virtual gorge, making collection of tolls especially attractive.

[2] Although some castles were owned by "robber barons in aristocratic clothing," the greater number were owned by a few major parties, in particular the Archbishops of Mainz, Trier, and Cologne, all of whom had permission from the Empire to charge tolls. Indeed, the ability to charge tolls was a much sought after emblem of political independence, from the thrall of feudalism. The location of castles was dictated by defensibility and command over travelers, which might necessitate owning castles on both river banks, particularly where the river widened. At St. Goar, the width of the river required castles on both sides. Pfalzgrafenstein, being located on an

There were certainly many non-cooperative tolls set, but cooperative gaming was also important. The purchase, building and positioning of castles, the attention paid to defensibility and credibility and the charging of tolls will be described as a game of strategy between these major actors.

However, there were other players as well, players who broke the Empire's rules. Such players could be found doing the following:

–operating a toll booth without permission

–charging a higher toll than authorized

Both these practices were called thelonia iniusta ("unjust toll") by contemporaries, and the historical record suggests that unjust tolls were rampant. In an era when the doctrine of just price dominated economic analysis, the injustice of excessive tolls was apparent. Even worse behavior occurred, such as robbing ships' cargoes or stealing the entire ship, especially in times of political disorder. These were capital crimes. Such behavior merited the terms "robber baron" (the robbers were usually low-ranking nobility) operating out of "robber castles," terms which were coined then and live on today. [Mueller-Mertens et al, p. 767]

One of the periods of greatest disorder in the Holy Roman Empire was the Interregnum, 1250-1273, when there was no Emperor. The number of tolling stations exploded after 1250, at least doubling in 4 years [Pfeiffer, p. 391]. These stations could not possibly have got permission from the Emperor, as there was none. The behavior of "robber barons" was clearly non-cooperative, and there was no central authority to deal with it. In response, a historically (for that time) unique coalition arose–the "Rheinischer Bund," the Rhine League. The League consisted of 3 types of members:

–Cities. These were the most numerous (100 in all), and included the two founding members, Mainz and Worms. The city members represent the interest of the merchants who run the cities; the merchants are heavy users of shipping. Thus, a rich merchant in Mainz, Walpod Arnold, is often credited with being one of the founders of the League. [Mueller-Mertens et al, p. 769; Buschmann, p. 169]

–Princely members. Every member in this category is nobility. The most prominent members are the Archbishops of Cologne, Mainz, and Trier–all of whom controlled castles and had the right to collect tolls. Other members of this category are identifiable toll charging castellans–the Count Palatine at Rhine Castle, and the Lesser Count at Andernach

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island, was able to cover the width of the river with a bow shot and its walls were never breached. However, there are few Rhine castles that never fell prey to enemy attacks, either by rival castellans or by armies formed to protect shippers' and authorized toll collecting interests.

Castle.

–Knightly members. These members are lower ranking nobility, but still in charge of a castle and having the right to collect tolls. These latter two categories totaled 30 members [Buschmann, p. 169]

The common interest of the Rhine League has been described as follows:

> "The League sought, through a general peace along the Rhine, for the security of trade routes and suppression of 'unjust' new tolls. The League further sought to reduce the onslaughts of the feudal lords through economic sanctions and the destruction of robber castles." (Mueller-Mertens, Paterna, and Steinmetz, p. 769; our translation)

The League was officially launched in July of 1254, and quickly set to work putting robber barons and their castles out of business. Four major robber barons were targeted, and at least 10 (possibly 11) robber castles were deactivated during the next 3 years. The list is impressive [Pfeiffer, p. 391]:

Robber Baron	Castle
Werner von Bolanden	Ingelheim, Sterrenberg
Phillip von Hohenfels	Boppard, Sterrenberg, Oberwesel, Trechtingshausen, Nakkenheim
der Herr von Eppstein	Braubach
Phillip von Falkenstein	Falkenau, Geisenheim (?)
Der Baron von Rietberg	Rietberg

To this extent alone, the League achieved its objective and justified its existence.

The League's very first significant military action involved putting together a sufficient force to besiege Werner von Bolanden at Ingelheim Castle. von Bolanden capitulated, and ceased charging unjust tolls. [Buschmann, p. 171] This set the pattern for subsequent successful actions.

The League action at Trechtingshausen offers an interesting lesson in castle siting. The toll station at Trechtingshausen that the League succeeded in shutting down was located at water's edge, making it easy to besiege. Robber baron von Hohenfels built a replacement castle, Reichenstein, in a hard-to-besiege location atop the rocky cliff overlooking Trechtingshausen. This castle, not taken by the League, was collecting unjust tolls as late as 1282, before it was razed for good by the next Holy Roman Emperor, Rudolf of Hapsburg [Pfeiffer, p. 306].

The League had one spectacular success against a robber baron who was not involved merely in collecting unjust tolls, but also in kidnapping. The Baron of Rietberg had kidnapped the wife of the King of Holland. The League, funded in large part by 500 silver Marks from the

City of Worms, captured Rietberg Castle and rescued the Queen of Holland in 1255. [Buschmann, p. 171].

With such remarkable success, it is somewhat surprising that the League survived for only 3 years. Accounts differ on exactly why the League lasted so short a time. All accounts point to the so-called Double Election of 1257, when the League split politically over the choice of Emperor between rival candidates, one English (Richard of Cornwall), one Spanish (Alphonse of Castille), neither of whom was elected. Since 3 of the 7 Electors of the Empire were members of the League, a split in the League over such an election had repercussions Empire-wide. Also implicated are the League's first military reverses. At the end of 1256 at Rheinfels, a costly siege by the League did not force the resident robber baron, the Count of Katzenelnbogen, to yield [Pfeiffer, 396]. Then, in 1257, that same Katzenelnbogen and his allies withstood an even costlier siege at Burg Selz. Thus, a combination of political divisions and military reverses spelled the end of the League.

However, in regional formations, such as the Peace of Worms of 1269, the principles espoused by the League lived on after its official demise [Pfeiffer, 399]. The principle of dealing with robber barons by destroying their robber castles was by now too successful and too well established to give up completely. Thus, when the new Emperor, Rudolf of Habsburg, besieged and later hung the highway robbers at Sooneck in 1282, and then torched the castle to put it out of business, he was following the strategy of the Rhine League [Pfeiffer, p. 418].

The authorized tolling stations of Rhine princes did not impoverish the Rhine.[3] Just the opposite occurred, as the fortifications tended to attract small business and accordingly, the local economy flourished. In the following, we explicitly focus upon pricing behavior along the Rhine during the period of the Rhine League. Demand for passage along the Rhine depended upon *total* tolls charged and intuition suggests the possibility of price instability or the choking off of travel and trade.[4] However, considering the possible Nash equilibria one finds numerous possibilities that depend upon information structures, reputations, relative strengths and so on.

The most natural extensive form for a repeated non-cooperative game leads to a solution in which the "price" of traveling the Rhine *rises* with increased rivalry and the discovery of oft-forgotten economic lore. The resulting Nash equilibrium for each period of the game is identical to one that Cournot applied to a (simpler extensive form) successive tolling problem in 1838.

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[3] No doubt they somewhat restricted passage, yet they also collected and spent money. They may have collected and invested more with lower cooperative tolls, but may not have had to spend as much locally, if cooperation meant little need for armies and fortification.

[4] Tolls, once paid, are sunk costs, so the next castle along a river has an incentive to charge a price independent of its neighbour's price. Further, for valuable cargo in transit, the demand to complete the trip may exceed the ex ante demand for the travel.

Cournot's solution later instigated debate and clarification from such eminent sources as Marshall (1920) and Stackelberg.[5] Not surprisingly, in light of modern game theory, disagreement on solution concepts to old market problems is to a large extent disagreement over the modelling of the game to be played.

One may examine the collusive equilibrium which was the ostensible purpose of the Rhine League. As with most collusive agreements, there were incentives to cheat on this agreement. These incentives could be dealt with in part by hostile takeovers--a more physical endeavor in those days--or by more subtle persuasion.

One may also examine a class of symmetric non-cooperative Nash equilibria. Such equilibria may be thought to be similar to buying a train or airplane ticket today, where the total price is negotiated through the toll-takers' representatives at the point of origin. This equilibrium concept need not depend on end point collection of tolls but only upon their advertisement and credibility. The important thing for equilibrium is that the *tolls*, however unconscionable, not be *revised after the trip commences*. As long as reputation is sufficiently important in a repeated game, castles may implicitly contract to abide by their stated tolls. Maintaining reputations in such games often requires an infinite, or *uncertain* horizon. Clearly, the length of the horizon of any tolling castle must often have been in doubt, given the finite tenure of the Emperor. Still, this repeated game rationale for maintaining implicit contracts allows us to look at pricing as if it were a one-shot game with explicit contracting. To such a model we now turn.

2. Single Period Toll Equilibria

Consider the demand for right of passage along a segment of a toll-way or river. In this case, demand is a function of all tolls, in particular, total demand for passage from point A to point B depends upon total tolls paid from A to B. This contrasts to the usual Bertrand-Edgeworth formulation of a price game. A model related to ours, but with more complications, is found in Karni and Chakrabarti (1997), who study the Silk Road.

Consider a finite number of castles (or defensible nodes), $n \in N$ in $[A, B]$, where each castle-owner charges his or her profit-maximizing toll. There are no problems of timing of production or inventories, since the commodity offered for sale, the "right to pass," is perfectly homogeneous. We take the location of the castles to be fixed; see Feinberg and Kamien (2000) for a recent treatment of the siting problem. Assume maximization of current period profits, in the sense that industry pricing policy permits firms to offer one-period enforceable contracts. Hence, value is not a discounted sum of profits, but an immediate payoff. Also, there is neither investment nor growth via merger in the short run.

[5] Edgeworth, Bowley and Wicksell also entered the debate, (see Schumpeter [1954, p. 983]).

Castles have full information and choose prices, such that $Q = D(P)$, where Q is total demand and $P = \sum p_i$, for $i = 1,...,n$. Pure competition prevails on the buyer's side of the market.

<u>Assumption 1</u>: D(P) is well defined and continuous. For all $P > 0$ there exists a $P^u > 0$ such that $D(P^u) = 0$ for $P > P^u$ and $D(P) > 0$ for $P < P^u$. Further, $D(0) = Q^u < \infty$, $P \varepsilon (0, P^u)$ and D is twice continuously differentiable with $D'(P) < 0$.

<u>Assumption 2</u>: Q is perfectly homogeneous. There is a fixed technology where input costs are given. The cost function for castle i, $C_i(Q)$, is well-defined and continuous for all $Q \geq 0$. However, without loss of generality, in what follows we shall assume: $C_i(0) \geq 0$, $C_i'(Q) \geq 0$ and $C_i''(Q) \geq 0$. For a prospective new castle there may also be positive fixed entry costs but these are assumed sunk for the existing castle stock.

Each castle (in a non-cooperative setting) chooses p_i with knowledge of D(P). This places an effective upper bound on each p_i of P^u. Now every castle faces its own demand function which gives the amount demanded of the castle as a (twice continuously) differentiable function of the prices of all the castles in the (local) market. The amount demanded of a castle is assumed to be both a decreasing function of the castle's own toll *and* a decreasing function of each of the other castles' tolls. Hence,

<u>Assumption 3</u>: The demand facing the ith castle is given by $Q_i = Q = D(P) \geq 0$.
From Assumption 1, D(P) is well-defined, continuous and bounded for all $P \geq 0$. Now, for all $i= 1,...,n$, if $p_i' > p_i'' \geq 0$ (and given other prices $p_j \geq 0$, for all $j \neq i$), this implies that:

$$D(p_i' + \sum_{j\neq i} p_j) < D(p_i'' + \sum_{j\neq i} p_j) \text{ or } Q_i' < Q_i''. \text{ This also implies } Q_j' < Q_j'', \text{ for } j \neq i.$$

Assumptions 1 and 2 allow us to write the profit function for each castle as:

$$\pi_i(p_1,...,p_n) = [p_i D(P) - C_i(D(P))],$$

which given the upper bound on each p_i, is itself bounded. Clearly, the profit function is also well-defined and possesses continuous second derivatives. The best-response Nash price reaction function for each castle i (PRF_i, hereafter) is the best response of the i-th castle to any given set of p_j's of the other castles. Hence, assuming interior solutions and price at least equal to marginal cost, we can write for each castle $i = 1,...,n$:

$$\partial\pi_i/\partial p_i = D(P) + p_i D'(P) - C_i'(D(P))D'(P) = 0.$$

The solution to this equation defines the PRF for castle *i.* Dropping the subscript for convenience, unique and global non-cooperative profit maximization for each firm will be implied by:

$$\partial^2\pi_i/\partial p_i^2 = 2D' + p_iD'' - C_i''D'' - C_i'D'' < 0, \text{ for all } i = 1,...,n.$$

As long as conditions of the implicit function theorem are satisfied it will be possible to solve for the p_i.[6]

We can illustrate the above points as well as various equilibrium concepts with the following simple example. As with Cournot's mineral spring, assume that along the Rhine River each castle's marginal costs are zero,

$$C_i' = 0.$$

Also assume that

$$D(P) = a - b(p_i + p_{-i}), \text{ where } p_{-i} = \textstyle\sum_{i\neq j} p_j.$$

Then,

$$\pi_i = [a - b(p_i + p_{-i})]p_i$$

and the first-order conditions yield:

$$p_i = (a - bp_{-i})/b$$

This yields the PRF for this castle, as a function of the prices charged by all other castles.

Invoking symmetry, we get that

$$p_I = a/[2(n+1)]$$

as the Nash equilibrium price for each castle.

[6] By reversing the role of price and quantity, the above conditions are sufficient for the existence of a Cournot equilibrium. Cournot himself used price equilibria with a single quantity as we do here. Stability further requires that $\partial^2\pi_i/\partial p_i^2 + \sum_{j\neq i} |\partial^2\pi_i/\partial_i\partial_j| < 0$, for all i,(assuming interior solutions). See Friedman (1977), chapters 2-4.

It follows that the total price paid by a traveler will be

$$P = na/(n + 1)b$$

and total quantity, number of trips, will be

$$Q = a/(n + 1).$$

A "reverse" symmetry with the Cournot mineral spring problem may be noted here.[7] For the same cost curves, and the following demand specification

$$D(P) = a - b(q_i + q_{-i})$$

the Cournot firm output is

$$q_i^c = a/(n + 1),$$

price is

$$p_i^c = a/(n + 1)b,$$

and industry output is

$$Q^c = a/(n + 1).$$

As n increases quantity converges to the horizontal intercept in a Cournot model. Price converges at exactly the same rate (adjusting for demand slope) in the non-cooperative tolling model described above. Price is not only rising, but for $n > 1$ it will always be above the monopoly or joint profit maximizing price of $P^m = a/2b$.[8] In Nash equilibrium, firm profits are

$$\pi_i = a^2/(n + 1)^2b$$

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[7] See Sonnenschein (1968) who discusses the formal equivalence between complementary monopoly and duopoly. Although they do not specifically deal with the problem of perfect complements, Singh and Vives (1984) provide a general treatment of the duality between Cournot competition and Bertrand competition. Their analysis shows that oligopolists selling complementary products will choose compete over price rather than output, in very much the manner we describe here.

[8] Clearly as the River becomes more competitive, or as n increases, these profits decrease.

and industry profits are

$$\Pi = na^2/(n + 1)^2b.$$

Incidentally, these are equal to the profits in the corresponding Cournot mineral spring problem.

The main finding is that, in the case of an n-firm oligopoly with perfect complements, the price is higher than for a monopoly or where one firm can control total output. Moreover, the total industry price increases as the number of competitors increases.

The problem faced by colluding parties in this context is how to get prices *down* to joint maximizing levels.[9] For instance, the Counts of Katzenelnbogen, the owners of Burg Rheinfels, had been charging tolls since 1185, but in 1245 they fortified the castle and increased their tolls drastically. This was an affront to the Empire; however, with the Emperor off in Sicily (indeed, the Emperors were rarely exercising direct influence on the Rhine Valley throughout the entire period 1175-1250), the affront was allowed to persist. Eventually the League of Rhine Cities entered the picture and laid siege to the castle. However, the increased fortifications proved effective and the castle successfully resisted overthrow. In this case, the League had to acquiesce to unjust tolls.

There are also other interesting issues that arise here. The League acted jointly and simply "eliminated" Reichenstein. One possibility that arises when joint maximization is effective is that the distribution of tolls across castles is based upon relative military strength, à la threat points in a Nash cooperative game.[10] Clearly the League is also a blocking coalition or at least attempting to be one, which would prove important should one model this as a cooperative game in coalition function form.

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[9] Unlike normal conspiracy models, buyers wish to ensure cartel stability, not undermine it. That is, "fusion" is unambiguously socially beneficial in this case and is to be contrasted to the case of joint profit maximization between successive monopolists, which useful though it may be in mitigating the effects of horizontal competition, may not be the ideal form of economic arrangement where there exist possibilities of achieving greater degrees of competition in several stages. See also, Marshall (1920, pp. 493-495) and Machlup and Taber (1960, p. 116).

[10] Since it is less expensive for at least some travelers to portage by a single castle than to go by land for the entire trip, a castle's maximum effective price may be constrained. Hence, if a single castle plays a duopoly game against a joint maximizing federation, the renegade castle's price may fall short of a duopoly price. Further, as the toll of a single castle rises, the value of its elimination rises. Similarly, a travelers' protection agency would find it less costly to protect travelers, the fewer the tolling stations involved. These factors alone suggest that a Rhine monopolist might operate several tolling locations (possibly have a mobile army in reserve). Naturally, shorter distance travel and price discrimination between longer and shorter travel also dictate numerous tolling stations.

3. Some Concluding Thoughts

In our view, the tolling model we have presented illuminates and clarifies the case of perfect complementary monopoly. Machlup and Taber (1960) distinguished "side-by-side" monopolists from the more commonly considered case of bilateral monopoly by the *necessity* of the monopolists to communicate and to possibly contract with one another.[11] The private toll-way, can be considered a case of perfect complementary monopoly.

There are 3 distinguishing characteristics of the model presented here that should be noted. First, with respect to sunk costs and the moral hazard problem, there do *not* exist any inventory possibilities and the costs of "holding out" are potentially much lower for the castles concerned (and higher for the traveler who cannot accumulate "travel coupons"). That is, a contract (a pre-travel agreement for travel in [A, B]) may be necessary to mitigate the sequencing advantage that "head-of-the-river" castles may have. This possibility in studied at length in Feinberg and Kamien (2000). Second, the monopoly (or contract) solution does not have the same indeterminateness with respect to division of the spoils as do other models of mutual interaction between producers. A contract would fix total price, P and therefore, total quantity, Q and total profits, Π. As argued, conditional on P being agreed upon, the distribution of military strength would yield a particular price distribution for the $p_{i.}$ This result arises because, in this case, quantity and price are determinate (equal to that generated by an integrated monopolist) and the fact that there is no "intermediate service" to be haggled over. Third, with respect to more traditional complementary monopoly models, there usually exist a finite number of inputs contributing to the final output (tires, batteries and engines for cars; cooper and zinc for brass, etc.). Accordingly, as is well known, the car or brass manufacturers may have incentives to integrate. Not so, in the model we have presented, as we haven't ruled out entry possibilities in any interval along the toll-way. In this sense, the buyer (traveler) is more liable to "hold-up" than other cases.

Be that as it may, the model presented above illustrates the existence of stable toll configurations where demand depends on the total price. The underlying example that we have employed is not as idiosyncratic as it may first appear. Consider end-to-end railroads, England's private toll roads, inter-country roads (or rivers), or American *interstate* toll roads. Part of the "deal" for interstate highway operators is essentially an agreement to cease tolling activity once construction costs have been recouped, although in 1988 New York State considered reneging on this agreement.

While the model presented has applicability to a variety of toll-taking scenarios, the analogy with vertically-related market power models is somewhat strained. There is no monopolist at one stage of a multi-stage production process selling all output to another monopolist at the next

[11] The most quoted example of complementary monopoly are manufacturers of copper and zinc selling their outputs to a brass producer (who combines the inputs in fixed proportions). See Cournot, Chapter 9.

stage, who in turn, intends to utilize that output in the one-to-one manufacture of his own product, and so on. (see Waterson [1984, pp. 83-85].) Indeed the results are significantly different. For example, if castles were mistakenly treated as though they were a vertical chain of monopolists and monopsonists as in the mineral spring example, then Nash equilibria are not well-defined, although bargaining equilibria may attain the simple monopoly price, $P^m = a/2b$. Alternatively, if castles are considered as competitive buyers and monopolist resellers, the result is identical to the sequential, subgame perfect equilibrium of the Stackelberg version of the model. That is, the first castle to set price receives $p_1 = a/(2b)$, the second $p_2 = a/(4b)$ and so on, with the n^{th} castle receiving $p_n = a/(2bn)$.

There is one vertical relationship that does bear a resemblance to our model. Suppose that there are n inputs to a final output production function. Further, assume that all these inputs are used in fixed factor proportions. Then horizontal competition between input sellers will be similar to the Nash equilibrium of the game described above.

For the standard interpretation of vertical links the model does not apply, although the analogy is not totally misleading. In the sense that markets may fail to coordinate vertical relationships, or downstream and upstream castles, the motives for contractual or collusive relationships to lower prices to a monopoly price is similar in both models (see Williamson, 1971; Hay, 1973; Blair and Kaserman, 1983).

Clearly, the results presented here could be extended. For one thing, one could consider explicitly a longer time horizon, as well as entry, exit (often by force of arms), alternative land routes, and the cost of military operations, in addition to pricing behavior. Reputations may also play a role in the sequential game, and at 2 levels. The Emperor has a reputation for maintaining the entire system; the absence of an emperor destroys this reputation. At the level of an individual castle, if such a castle finds that its long run reputation is less important and knows that a traveler has already incurred sunk costs, then a signalling model applies (Kreps and Wilson, 1982).

Regardless of the level of technical detail, the basic tension between individual and group rationality is well exhibited by viewing castellans as rational economic agents. The difference between Nash equilibrium and group optimum of the game played by castellans could hardly be greater.

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