The Emergence of Property Rights Enforcement in Early Trade:
A Behavioral Model Without Reputational Effects

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ABSTRACT

The present article focuses on the conditions that allow governments to increase property rights protection because they expect enough income from such action. We develop a behavioral explanation, according to which the answer lies in the growth in the importance, size, and wealth of merchant guilds in the medieval era in Western Europe as well as a somewhat surprising effect of volatile price structures. We add to prior research by showing that even uncoordinated embargo pressures among multiple guilds could get medieval rulers to offer high levels of property rights protection.

The Emergence of Property Rights Protection in Early Trade:
A Behavioural Model Without Reputational Effects[1]

Since property rights are known to be a key to the success of any complex social organization, their attainments and preservation are of great interest. Prior research has converged on the conclusion that property and individual rights will be under-supplied and over- priced in the sense that the taxes levied by governments will be way too high for efficient markets to develop. However, we also know that markets affected by the generic inefficiency associated with governments' monopolistic protection of property rights are likely to emerge and actually prosper.

The present article aims to advance research on this important set of issues by addressing the following question: what brings about the conditions that allow governments to increase property rights protection because they expect enough income from such action? We develop a behavioral explanation, according to which the answer lies in the growth in the importance, size, and wealth of merchant guilds in the medieval era in Western Europe.

Our explanation for the emergence of property rights protection adds to prior research by exploring the importance of guild stability and the effect of uncoordinated embargo pressures among multiple guilds. We also examine the effect of volatile price structures, a possibility that has gone unnoticed in previous attempts to explain the emergence of property rights enforcement. Remarkably, volatile price structures are going to play a starring role in our explanation of the emergence of property rights.

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The article is organized as follows. Section 2 below presents a brief review of the literature, section 3 introduces the model, section 4 accounts for our findings, and section 5 offers a discussion and concludes the essay.

2. Background

A central question in economic history concerns the expansion of markets prior to the emergence of a state with sufficient power to ensure that contracts and property rights were enforced (Knight 1992, Greif 1993, Greif et al. 1994, Sened 1995 and 1997).[2] In some European regions, as markets expanded, local medieval rulers gained sufficient powers of property rights enforcement to fulfil the rudimentary functions of the state (Greif et al.). The fiscal basis of these advances in the delineation and enforcement of property rights was revenues gained from the medieval tax system emerging between the 11th and 13th century (Ames and Rapp 1977, Becker 1966; Biddick 1985, Bonney 1999, De Long and Shleifer 1993, Kedar 1974).

As markets emerged during the Middle Ages, a local ruler faced the temptation to abuse the property rights of merchants who frequented his town (Greif 1992, Greif et al. 1994, Landa 1981) as well as the property rights of citizens through taxation, which in effect was a monopoly on theft (De Long and Shleifer). Even if rulers and traders had a common interest in securing a high level of property rights enforcement, short-term feedback and self-interest conspired against securing traders' rights. According to previous research, an institution that *ex ante* committed the ruler to secure the rights of alien merchants was necessary if these traders should dare to frequent a ruler's territory (Greif 1992, Greif et al. 1994). Obviously, the absence of such institutions led to impediments of trade and efficiency.

[2] Incidentally, Greif's emprirical account of the Maghribi traders is challenged by Edwards and Ogilvie (2008), who argue that there is no clear evidence for Maghribi coalitions. Edwards and Ogilvie maintain that these traders made use of a statutory legal system and took disputes before courts of law.

It has been shown that simple bilateral or multilateral reputation mechanisms alone could not support an efficient level of trade (Greif 1992, Greif et al. 1994). However, in combination with a particular form of organization, the guild, it has been conjectured that the outcome could reversed (Greif 1992, Greif et al. 1994). According to this conjecture, if future trade was conditioned on past conduct, the guild might help the ruler to commit to honour the merchants' property rights. To overcome the ruler's commitment problem, Greif (1992) and Greif et al. (1994) argued that there was a need for an organization with an ability to coordinate the traders' responses and to ensure the traders' compliance with decisions to embargo particular rulers. Based on historical evidence, Greif (1992) and Greif et al. (1994) identified the merchant guild as an institution with these attributes. A guild organization could have supported the expansion of trade to its efficient level only if it had the ability to coordinate embargos when its members' property rights were abused and if it was able to ensure that these responses became effective.

During the Middle Ages, when the guilds were instrumental in expanding trade (Greif 1992, Greif et al. 1994), it is questionable if the many different guilds actually could achieve the required coordination of individual responses. Neither is it plausible that very large guilds could have secured traders' property through informal means of contract enforcement (Cooter and Landa 1984). As a group expands, the personal relations that support informal means of contract enforcement at some point become too weak (Cooter and Landa 1984, Sened 1997). It is therefore not realistic that many different groups that represented many individual members would be able to achieve a level of coordination required to pressure rulers to respect and enforce property rights.

This observation undermines a critical assumption in prior game-theoretic explanations of property rights enforcement. Prior explanations have assumed that widely distributed groups of (thousands of) traders were somehow able to coordinate response by communication. However, delays and error in communication seems to weaken, if not undermine, this assumption, both in

current and historical cases. In consequence, we propose a behavioral model that does not require such an assumption of effortless coordination among traders organized in groups. The groups involved are merchant guilds from the medieval era. As in prior research (Greif 1992, Greif et al. 1994), these guilds have a central role in our explanation, but it is behavioral adaptation among multiple guilds rather than the concerted action of one large guild that drives our results.[3]

3 The model

3.1 Towns, goods and traders

There is a fixed population of fifty traders travelling between five towns. In time-step one, each trader is endowed with an initial stock of wealth and is placed at random in one of the five towns. In each town, five goods are traded.[4] After the initial random assignment of location, the traders move, in random order, according to their estimate of optimal trading routes.

Traders hold an amount of a good and decide to travel to a different town and sell the good to obtain an income. This decision is based on the current maximum price differences. There is a random walk in prices, so in each time-step, prices adjust up or down at random. The trader does not take any expectation of random fluctuation in prices into account and relates to current prices only. As we shall see, the short-term fluctuation in prices is going to play an unexpected role on our explanation of the emergence of property rights. Given his current location, as well as the current prices and levels of property rights enforcement and taxes, each trader estimates the maximum

[3] Our definition of merchant guilds is taken from Greif et al.,who claim that merchant guilds exhibited a range of administrative forms, from subdivision of a city administration to an intercity organization, with a shared common function that enabled rulers to overcome the commitment problem. The mechanism underlying this function was the guilds' ability to coordinate embargos if its members' property rights were abused and, through exclusion and other internal enforcement mechanisms, to ensure that the guild members' honoured these embargos.

[4] The results are robust; we obtained similar results with simulations with different numbers of traders, towns and goods.

expected income from moving between the current town and any possible combination of the next two locations (including returning to his own current location).

Having estimated all the possible combinations of trading the five goods at the next two locations, the trader chooses the optimal route. In the next time-step, the trader moves to the town that lies on this estimated optimal route. Arriving at the new town, the trader receives the returns from selling the good he is carrying, net of tax and loss due to imperfect property rights enforcement. In each time step, the trader repeats the estimation of the optimal route and along the way possibly adjusts the good that he had planned to exchange and the route he had planned to travel.

If the trader is a guild member, this estimation should exclude any towns embargoed by his guild. Guild members may have to forgo the optimal travelling route and therefore decide to break an embargo. The guild member breaks the embargo if he has decided this is a possibility, if he can obtain higher income from breaking the embargo, and if he observes that other independent traders, on average, are probably better off. The trader's opportunism variable gives the point probability that determines whether it is a possibility to break an embargo.

Breaking an embargo is a serious matter, however, because a guild member that breaks an embargo is immediately excluded from his guild, never to be readmitted. For this reason, a trader carefully considers whether independent traders are wealthier than guild members. The trader estimates a confidence interval and only breaks the embargo if the probability that he will be better off than the average independent trader is higher than 0.95. Whether this will be the case partly depends on the guild size. The guilds have some bargaining power, depending on their size. As shown in Appendix 1, a member of a large guild will therefore meet a favourable treatment by the ruler in terms of a slightly higher level of property rights enforcement than members of small guilds

experience. According to previous research (Greif et al. 1996), rulers were able to discriminate between traders and provide selective treatment. Our model therefore includes this effect.

Note that our model with fixed guild membership assumes that the strategic behavior of players is an equilibrium behavior even though we do not demonstrate that this is the case. In our models with adjustable guild membership, guild members defect if it is highly probable that the gains of defection will be higher than the loss. We thus capture individualized strategic considerations in the probability that an embargo breaker will be better off than a guild member. This probability is computed for each individual guild member in each time step.

3.2 Rulers

A ruler resides in each of the five towns. The rulers collect tax and enforce property rights. In time-step one, each ruler receives a fixed tax-level and an initial property rights enforcement level. The tax-level was set to 0.10, and the initial property rights enforcement level was set to 0.50. This means that a trader looses 50% of his goods in a town because of pilfering. The tax level is realistic according to the historical record (Ames and Rapp 1977, Bonney 1999, Greif et al. 1994). In England, for example, a tax of about 10% was imposed on movable property in the 13th century (Ames and Rapp). However, property rights enforcement levels were set to an unrealisticly low value in order to examine whether the model could support an increase.[5]

The rulers enjoy two sources of income, tax and a share of the pilfering that occurs when the enforcement of property rights is lax. Each ruler has an army that enforces property rights to the goods that are traded in the town and helps back up tax collectors. The level of property rights

[5] Taxes became an increasingly important fiscal basis for rulers' revenue during 11th to 13th centuries (Ames and Rapp 1977, Becker 1966, Kedar 1974). Movable wealth was taxed in England from the mid-12th century (Biddick). As regards property rights enforcement levels, there is evidence that these taxes significantly weakened with proximity from markets and distance to major roads (Biddick 1985), an effect that we do not take specifically into account (it is included in our summary measure of the property rights enforcement level).

enforcement depends on the size and quality of the army. The ruler always has a minimal army that ensures he can collect taxes and protect his own wealth, but in order to increase the level of property rights enforcement, the ruler must spend additional amounts of income on the army (or police force). The level of property rights enforcement therefore depends on the level of costs that the ruler spends on the army, a realistic assumption (Ames and Rapp 1977, Bean 1973, Becker 1966, Bonney 1999, Kedar 1974).

Property rights can be perfectly enforced, in which case traders receive all income from trade net of tax. Property rights can also be imperfectly enforced, in which case traders lose a proportion of their income (the rulers capture part of this income). In the extreme case, there is zero enforcement of property rights, in which case traders lose all of their income. Based on a number of the previous periods, the ruler chooses a level of property rights that maximizes his level of income. The ruler is quite sophisticated in basing his estimate on correlations of the historical levels of property rights enforcement and income.

For each of the last ten time-periods, the ruler notes the level of property rights enforcement in his town and his total revenue net of costs to property rights enforcement. The costs of maintaining a given level of property rights enforcement was set to 90% of the tax rate, which was set to 0.10. That is to say, the ruler, in each time-step, receives an income of 0.01 of the total value of trade in his town in this time-step. That is, most revenue goes to financing the ruler's army, which is consistent with the historical record (Ames and Rapp 1977, Bean 1973, Becker 1966, Bonney 1999, Kedar 1974).

The ruler then estimates the coefficient of correlation between the levels of property rights enforcement and the revenues net of costs. If this correlation is significant (at the 0.05 level) and positive, the ruler infers a positive relation and adjusts his current goal of property rights enforcement upwards with an increment of 0.02. Should the upper boundary of 1.00 be reached, this

level of property rights enforcement is maintained as the goal. By contrast, if the coefficient of correlation is significant (at the 0.05 level) and negative, the ruler infers a negative relation and adjusts his current goal of property rights enforcement downwards with an increment of 0.02. Should the lower boundary of 0.00 be reached, this level of property rights enforcement is maintained as the goal.

It may be the case that the ruler computes a correlation coefficient of zero or experiences zero revenue. In this case, the ruler experiments by adjusting the current level of property rights enforcement according to a normal distribution with mean zero and std. dev. 0.005. The ruler is initially assigned a goal of property rights enforcement of 0.50 and then adjusts the current level of property rights enforcement (Enf_{Level}) towards the new goal (Enf_{Goal}):

$$(1) \qquad Enf_{Level} = (1-\alpha_R)\, Enf_{Level} + \alpha_R\, Enf_{Goal}, \;\; \alpha_R = 0.50$$

The reason that the adjustment is not instantaneous is that there is some friction in the adjustment towards a new goal. For example, it takes time to recruit and educate the new men necessary to expand the ruler's army. The ruler's net revenue in a time-step is given by

$$(2) \qquad (\tau - c*Enf_{Level} - \gamma) \sum p_{ij}(q_{ij}),$$

where $\sum p_{ij}(q_i)$ is the price p_{ij} of q_i amounts of good i sold in town j. The sum is taken over all the traders that pass through the town in a time-step. Thus, if zero traders pass through the town, the net revenue is zero. τ (=0.10) is the tax rate, and c is the ruler's cost of maintaining a particular enforcement level (Enf_{Level}). As in Greif et al. , we assume that trade is profitable and set $\tau > c*Enf_{Level} + \gamma$. γ is a coefficient of the guild's bargaining power as shown in Appendix 1.

We further set the trader's cost of maintaining a particular property rights enforcement level to zero. A positive cost on part of the trader is omitted because it is just a rescaling of *c*. The net revenue over time can be determined as the discounted sum of the periodic revenues. As can be seen from equation (2), the ruler can increase his net revenue by reducing the cost of maintaining a high level of property rights enforcement, $c*Enf_{Level}$. Unless the traders reduce the volume of trade by embargoing the city, the ruler would see a short-term advantage in reducing the level of level of property rights enforcement. The problem then is to ensure that the guilds can maintain an embargo pressure that is sufficient for the ruler to see an advantage in increasing and maintaining a high level of property rights enforcement.

3.3 Models with fixed guild membership

Fixed membership refers to models in which a proportion of the traders, throughout the simulation, remain members of the guilds they are assigned to in the initial time-step. The purpose of the models with fixed guild membership is to provide a baseline estimate, controlling for the proportion of traders who are members of a guild. We estimated models in which the following fixed proportions of traders were members of a guild: 0 of the traders (0 guilds), 1/3 of the traders (5 guilds), 2/3 of the traders (10 guilds), or all traders (15 guilds). The number of guilds in parentheses is averages of the guilds that emerged on the basis of the trader ethnicity and tolerance variables (see the description in the section below).

In all models, the role of the guild is to help rulers increase the level of property rights enforcement by embargoing towns that have disappointingly low levels of property rights enforcement. Property rights enforcement varies between zero (absence of enforcement) and one (perfect enforcement). An embargo is modelled as the probability that a guild member will stay away from a town. This probability varies inversely with the level of property rights enforcement.

In the case of perfect enforcement, the probability that a trader will stay away from the town is zero, and in the case of absent enforcement, a trader will stay away with probability one.

The guilds have developed a rather sophisticated embargo strategy. First, the guilds determine the level of property rights enforcement in the five towns. Second, the guilds *always* embargo towns that decrease the level of property rights enforcement over two consecutive recent periods (punishing relative relapse) and the guilds *never* embargo towns that increase the level of property rights enforcement over two consecutive periods (rewarding relative improvement). Third, among the towns that have not increased or decreased the level of property rights enforcement over the two most recent periods, the guilds reward high absolute levels of property rights enforcement and punish low absolute levels. In particular, guilds do *not* embargo the two towns with the highest level of property rights enforcement, the town with the median (third-highest) level of property rights enforcement is embargoed with probability 0.50, and the two towns with the lowest level of property rights enforcement are always embargoed. Finally, a town that has increased the level of property rights enforcement above 0.95 is never embargoed.

The virtue of the chosen embargo strategy is that it provides clear and consistent signals to the rulers and the guilds usually have at least two towns that are not embargoed and therefore can be used to sustain trade.[6]

3.4 Models with adjustable guild membership

We simulated two models with adjustable guild membership. In the first model, fifty traders receive randomly assigned ethnicity, tolerance and opportunism instincts, and variables, qualities that control guild membership. In time-step one, traders receive an ethnicity value, a tolerance instinct, and an opportunism instinct. Ethnicity is assigned according to a uniform distribution taking values between zero and one. The

[6] This embargo strategy is robust to increases in the number of rulers.

tolerance and opportunism instincts are positive values that are assigned according to a normal distribution, *N(μ, σ)*. Ethnicity remains fixed throughout the simulation. In the first time-step, tolerance and opportunism variables are assigned to the traders simply by copying the instincts. These variables change value when traders are members of a guildand throughout a trader's life. The formation of guilds is based on ethnicity, which is consistent with prior observations in the literature (Carr and Landa 1983, Cooter and Landa 1984, Greif 1992, Greif et al. 1994, Landa 1981).[7] In time-step one, the traders located in the same town establish guilds on the basis of their ethnic differences. A guild may include members whose ethnic differences are less than each of the members' tolerances of ethnic difference. In the commonly occurring case that a trader can become a member of more than one guild, he chooses to become a member of the guild whose mean ethnicity is closest to his own ethnicity. It may also be the case that a trader cannot be accepted in any guild because the difference between his ethnicity and the guild members' ethnicity is too large.

Similarly, a trader may not want to be a member of any guild, even if he could, because the ethnic deviation to any guild is larger than he can tolerate. For this reason, the tolerance variable determines how many and how large guilds will emerge in time-step one. The higher the tolerance variable, the more traders will be organized into guilds and the larger the size of the guilds. As tolerance decreases, there will be many small guilds as well as a number of independent traders with an ethnicity that deviates beyond what can be tolerated by any guild.

The opportunism variable determines whether the trader will break the embargo called by a guild provided this is advantageous. If a guild member breaks an embargo called by his guild, he is excluded and can never regain membership of this guild.[8] He may, however, obtain membership in an alternative guild. Guild membership can only be obtained by an actual meeting between a guild-

[7] Landa provides a seminal treatment of ethnicity as a basis for the clustering of trading groups that can support efficient levels of trade in countries with weak contract law.

[8] The punishment of withdrawal from future trade as well as expulsion are common economic sanctions in trading groups (Landa).

member and an independent trader (they need to be in the same town). As mentioned above, an independent trader becomes a guild member on the basis of the deviation between tolerance and ethnicity (for guild members as well as the would-be member).

One model of guild culture is a meritocracy. For individuals in guilds, the tolerance and opportunism variables incrementally approach the weighted mean level of guild tolerance and opportunism,[9] which adjusts in the following way. First, the guild members' wealth shares are estimated. These wealth shares are used to determine the weighted mean level of guild tolerance and opportunism. That is to say, more wealthy guild members have more influence on the guild's cultural climate, in terms of tolerance and opportunism. Second, each of the individual members' tolerance ($tol_{Individual}$) and opportunism ($opp_{Individual}$) variables incrementally approach the weighted mean level of the guild's tolerance (tol_{guild}) and opportunism (opp_{guild}):

$$(3) \qquad tol_{Individual} = (1-\alpha)\, tol_{Individual} + \alpha\, tol_{guild}, \; 0 \leq \alpha \leq 1,$$

$$(4) \qquad opp_{Individual} = (1-\alpha)\, opp_{Individual} + \alpha\, opp_{guild}, \; 0 \leq \alpha \leq 1.$$

[9] This introduces an element of endogenous personality or preference formation, with significant effects. In another, very different, model of institutional evolution, we show that such endogenous effects are also important (Hodgson and Knudsen 2004).

An alternative model of guild culture is a tenure-based, traditional culture. In this model, the weighted mean level of guild tolerance and opportunism was estimated on the basis of tenure. Guild members with longer tenure have more influence on the guild's cultural climate, in terms of tolerance and opportunism, than members with less tenure. A further difference is that adjustment rates (α) were distributed around some mean value in the wealth-based adjustment model, whereas the adjustment rates (α) were identical for all traders in the tenure-based adjustment model.

According to the simulation results, identical and positive adjustment rates promote enduring guild membership and stability through cultural adaptation in the tenure-based adjustment model. This is important because enduring guild membership and stability translate into higher embargo pressures. By contrast, heterogeneous and distributed adjustment rates promote enduring guild membership and stability through selection in the wealth-based adjustment model. Thus, depending on a guild's specific institutional arrangement there are different routes to the membership endurance and guild stability required to produce embargo pressures that can significantly increase the levels of property rights enforcement. The trader's net revenue in a time-step is given by

$$(5) \qquad (Enf_{Level} + \gamma - \tau)\, p_{ij}(q_{ij}),$$

where $p_{ij}(q_i)$ is the price p_{ij} of q_i amounts of good i sold in town j, τ (=0.10) is the tax rate, and γ is a coefficient of the guild's bargaining power as shown in Appendix 1 (when property rights enforcement approaches 1, γ approaches 0). As in the case of the ruler's revenue, the traders' net revenue over time can be determined as the discounted sum of the periodic revenues. As can be seen from equation (5), the trader can increase his net revenue if the ruler increases the level of property rights enforcement, Enf_{Level}. In order to help the ruler do this, the trader will have to embargo a town j and instead sell his goods in town k until $(Enf_{Level} + \gamma - \tau)\, p_{ij}(q_{ij}) > (Enf_{Level} + \gamma - \tau)$

$p_{ik}(q_{ik})$. Unless the guild can ensure that opportunistic traders, at a cost, forgo the temptation to increase their revenue by breaking an embargo, the embargo pressure will weaken and the ruler will not increase Enf_{Level}.

3.5 Sequence of events

(0) Assignment of variables and initial formation of guilds. The trader is assigned an initial location at random and possibly becomes a member of one of the guilds in his town.

(1) Each trader decides to invest his wealth in one good and estimates the optimal trading route. The guilds decide what towns, if any, they are going to embargo in the next time-step.

(2) The trader moves to another town, possibly breaking an embargo called by his guild, and sells the good he has invested in. In consequence, the trader and the ruler both receive an income.

(3) Traders who break an embargo are immediately excluded from their guild and can never be re-admitted in this guild.

(4) The ruler decides the level of property rights enforcement he aims to implement, and the level of property rights enforcement begins to adjust towards this goal.

(5) Guilds consider, on the basis of the observed behavior of the rulers', what towns, if any, they are going to embargo in the next time-step. Also, in models of adjustable guild-membership, the guild members' opportunism and tolerance levels are adjusted.

3.6 Calibration and robustness

The first noteworthy observation was the remarkable difficulty we had in establishing a working model. Even if all the traders were assigned a fixed guild membership, the embargo pressure itself was often insufficient to secure a significant increase in the level of property rights enforcement

over the rather low initial level of 0.50. Recall that a property rights enforcement level of 0.50 means that a trader looses 50% of his goods in a town because of pilfering.

In order to improve the model, the first difficulty we had to solve was to model the ruler's decision algorithm in a way that provided robust estimates of his choice variable (property rights enforcement). A major difficulty here was the large fluctuations in the volume of trade that happened because of the changes in prices and the adjustments in property rights in the other four towns. Initially, we had the rulers estimate a quadratic curve that fitted income as a function of property rights enforcement for a number of the previous periods. It became clear, however, that this and many other procedures were much too sensitive to the fluctuations in the volume of trade.

Finally, we inferred that the significant correlations between income and property rights enforcement provided an estimate that was sufficiently robust to yield useful estimates even in the case of large fluctuations. The question, then, was how many past periods should be included in the estimate of the correlation between income and property rights enforcement. After a number of sensitivity tests, it became clear that about ten to twenty periods provided the best estimate. In the simulations reported here we have set the number of past periods to ten. That is to say, in each time-step, the ruler estimates the correlation between income and property rights enforcement for the previous ten time-steps. As mentioned above, if this correlation is significant (at the 0.05 level) and positive, the ruler infers a positive relation and adjusts his current goal of property rights enforcement upwards with an increment of 0.02. A negative correlation leads to the opposite conclusion of adjusting the current goal of property rights enforcement downwards with an increment of 0.02.

A final issue to be decided regarding the ruler's decision algorithm was the incremental adjustment *of* the goal and the incremental adjustment *towards* this goal. A number of sensitivity tests had showed that the adjustment of the enforcement goal should use increments between 0.01

and 0.03. We therefore chose the increment of 0.02. Our tests further showed that the adjustment towards the goal should not be instantaneous. We therefore chose the adjustment procedure shown in equation (1), which is appropriate in any realistic case where some friction in the adjustment towards a new goal will always be present. In this case, and provided the rulers used the correlation procedure and adjusted the goal in small increments (e.g. of 0.02), the incremental adjustment procedure yielded a response that sometimes resulted in significant increases in the level of property rights enforcement.

Figure 1 here

Figure 1 shows a typical successful run of the standard model, as described here. In addition to considerations regarding the ruler's decision algorithm, the standard model also includes considerations regarding the guilds' embargo procedure and the level of price differences and variance in prices. According to Figure 1, obtained with the standard model and using adjustable guild membership, it is possible, over 500 time-steps, to increase the average level of property rights enforcement from 0.50 to over 0.90 in the five towns.

In terms of realism, a time-step includes buying a good in one town, moving to the next town and selling the good in this new town. Historically, the guilds emerged between 1200 and 1300 (Black 1984, Mackenney 1987, Renard 1918, Shepheard 1978, Smith 1972). If we think of a time-step as the average time involved in trading and travelling between two towns, a period of about two weeks seems a reasonable lower bound on the estimate of one time-step (depending on the distance to market). The 500 time-steps shown in Figure 1 are thus equivalent to a period of about

nineteen years or more. All simulations that are reported in the following are based on 1000 time-steps. The reason for this choice is that the level of property rights enforcement, as in the simulation shown in Figure 1, had usually reached a stable level between 500 and 900 time-steps. This observation is based on a very high number of simulations, obtained to assess robustness. As shown in Figure 1, a level of property rights enforcement of ovr 0.90 emerged during the first 500 time-steps and was then sustained for the next 500 time-steps. Our results thus report the emergent stable levels of property rights enforcement.

A further difficulty, that of the guilds' embargo strategies, was mentioned above. We tried, without much success, various simple embargo strategies, but none resulted in a significant increase in the level of property rights enforcement. It thus became clear that an effective embargo strategy must provide consistent positive feedback to those towns that increased their level of property rights enforcement and negative feedback to those towns that decreased their level of property rights enforcement. In addition, the guilds should adopt a "carrot and stick strategy." They should avoid embargoing the two towns with the currently highest level of property rights enforcement, and they should provide incentives to the town with the third-highest level of property rights enforcement by embargoing this town with probability 0.50. In this way the guilds ensured that some opportunities of exchange were always open while providing incentives for improvement of the median town. A further advantage of the devised embargo strategy is that it is robust. Given a sufficient amount of time, it worked for any number of towns between six and twenty as evidenced in additional simulations obtained to assess robustness.

A final issue concerns that amount of the stolen goods that are captured by the ruler of a town. The amount of stolen goods depends on the level of property rights enforcement. If, say, the level of property rights enforcement is 0.60, then 40% of all the trade in a town is lost because of pilfering. A share of these stolen goods may also be a source of income for the ruler. For over two thousand

years this question of diminishing the anticipated cargo of traders has been a source of conflict over property rights and a stumbling block for explanations of self-enforcing property rights (Knight).

To assess the effect of the ruler's capture of stolen goods, we simulated four variations of the baseline model in which the ruler's capture of the stolen goods was 0%, 10%, 50% and 100%. In the case where the ruler captured all of the stolen goods, he would obviously have an incentive to increase the level of property rights enforcement to increase the volume of trade, but he would have a disincentive to increase the level of property rights enforcement beyond a level that decreased his total income, including the capture of stolen goods.

Finally, we noted that during the 13th century, when guilds emerged, there was a medieval population-growth that expanded the demand for life's necessities more rapidly than supply could increase (Fischer 1996). As a result, prices kept rising to the extent that David Hackett Fischer has termed this period the medieval price-revolution. Not only did prices soar, but soon a growing instability emerged; the standard deviation of prices increased dramatically throughout the 13th century (Bailey 1998, Fischer 1996).[10]

In order to be consistent with the historical record, we chose to set the price level to 5 units and then defined a medium price variation as a standard deviation in prices of 4.5, a high price variation as a standard deviation in prices of 9.0 and a low price variation as a standard deviation in prices of 1.0. This definition is roughly consistent with the prices in silver shillings of oxen and wheat during the 13th century (Fischer). Moreover, the variation in prices for many goods during the 13th century had levels between what we here define as medium and high (Bailey 1998, Fischer 1996).

[10] The social effect of small variations in climate was amplified by the growing imbalance between population growth and a shortage of resources. Thus harvest fluctuations led to high fluctuations in prices. To this were added monetary disturbances, including recoinage and debasement, growing instability in exchange rates, and financial instabilities leading to a shortage of credit (Bailey 1998, Fischer 1996).

4 Results

4.1 Results of simulations with fixed guild membership

The first results come from our baseline model with fixed guild membership. In this model, a proportion of the traders, throughout the simulation, remain members of the guilds they are assigned to in the initial time-step. We estimated models in which the following fixed proportions of traders were members of a guild: 0 of the traders (0 guilds), 1/3 of the traders (5 guilds), 2/3 of the traders (10 guilds), or all traders (15 guilds).

As can be seen from Figure 2, the short-term variation in prices, surprising to us, turned out to play a major role as a co-determinant of property rights enforcement levels. Not only is this finding surprising within the context of the present study, but as far as we know, previous research has not in its own right considered price variation as an important determinant of the emergence of self-enforcing property rights (Carr and Landa 1983, Cooter and Landa 1984, Greif 1992 and 1993, Greif et al. 1994, Knight 1992, Landa 1981, North 1990; North and Thomas 1973, Sened 1995 and 1997).

Consider the case of medium price variation as shown in panel II of Figure 2. In this case, when zero traders are organized in a guild, the level of property rights enforcement does not, over 1000 time-steps, increase significantly above the initial level of 0.50 even if the ruler's capture is set to zero. As the ruler's capture increases, the combined effect of competition between towns and the loss of capture further drives down the level of property rights enforcement. A minimum level of 0.45 is reached in the case where the ruler captures all the loss on property rights enforcement. As 1/3 of the traders are organized in guilds, their embargo pressure drives the level of property rights enforcement up to 0.71 in the case where the ruler's capture is set to zero and 0.61 in the case where

the ruler captures all the loss on property rights enforcement. We thus see the expected joint effect of embargo pressure and capture.

Increasing the proportion of traders organized into guilds from 1/3 to 2/3 does not have much effect. As the proportion of traders organized into guilds is further increased to include all traders, however, we see the expected effect of the increased embargo pressure. Now, the level of property rights enforcement, on average, has increased to between 0.81 and 0.83 in about 500 periods, and this level is sustained throughout the remaining 500 periods of the simulation. In the case where the embargo pressure increases to its optimum, we also see that the capture effect is completely overpowered by the embargo effect.

Now, consider the case of high price variation as shown in panel III of Figure 2. In this case, the embargo pressure first begins to have some bite when 2/3 of the traders are organized into guilds, and at this proportion, we also see a significant capture effect. As the capture decreases from one hundred percent to zero, the level of property rights enforcement increases from 0.37 to 0.56. As the proportion of traders organized into guilds is further increased to include all traders, we see a dramatic effect. Now, the capture effect is not significant and the level of property rights enforcement reaches an average of between 0.96 and 0.97. This very high average of (almost perfect) enforcement of property rights is sustained throughout the last 10% of the simulation or more.

Figure 2 here

Finally, consider the case of very low price variation as shown in panel I of Figure 2. In this latter case, neither the embargo pressure nor the capture effect results in much difference in the level of property rights enforcement. No matter what proportion of traders are organized in guilds, property rights enforcement reaches a stable level of between 0.60 and 0.69. This level is higher than the initial level of 0.50, and it is reached solely because of competition between the towns.

The role of price variation, then, is to eliminate the feedback to rulers that comes from the competition among towns in attracting traders. Under high price variation, the feedback to rulers also becomes stronger. As can be seen from Figure 2, very high levels of property rights enforcement of between 0.96 and 0.97 are reached in this case. That is to say, a regime of very high price variation can lead to the emergence of almost perfect property rights enforcement. When the guild membership is fixed for the entire run, it is possible that the embargo pressure of guilds, even in the absence of explicit coordination between many small guilds, can lead to the emergence of high and stable levels of property rights enforcement.

Fixed guild membership is not a very realistic assumption, however, because individual opportunistic guild members would be prepared to break an embargo, even at the cost of being excluded, if the gains were sufficiently high. The problem we have to consider is whether a more realistic model with adjustable guild membership and high levels of opportunism can lead to the guild stability required to make the embargo pressure effective. This problem is considered in the two following sections.

4.2 Results of simulations with adjustable guild membership

The tolerance variable influences the number of guilds that emerge; the higher the tolerance, the higher the number of traders that become guild members and the lower the number of guilds. As the

tolerance level increases, all traders in each town become members of a few larger guilds. The tolerance variable also influences guild size by determining whether traders who have lost membership in one guild can be admitted in a new one. In addition, the opportunism variable influences how the guild sizes and number will adjust over time. The higher the opportunism, the more guild members will break an embargo and be thrown out. Gradually, a guild will become smaller and eventually it may cease to exist; the higher the opportunism, the faster the drive towards the elimination of the guilds. It is more difficult to establish guilds that can sustain an embargo pressure when the traders' tolerance is low and the opportunism high.

Panel I of Figure 3 below shows the results for the model with cultural adjustment. In this model, as in all the other models with adjustable guild membership, the price variation was set to the medium value of 4.5. Cultural adjustment is the gradual adjustment of the guild members' opportunism and tolerance to the weighted mean level of guild tolerance and opportunism. The weights in the first model are based on the guild members' wealth shares. As can be seen, low levels of opportunism promote higher levels of property rights enforcement. Moreover, as tolerance increases from an average of 0.03 to an average of 0.40, property rights enforcement also increases. As tolerance increases, more traders are organized in guilds, and as opportunism decreases, fewer members break an embargo. In consequence, the embargo pressures become stronger and the levels of property rights enforcement increase. If tolerance becomes very high, however, only a very few large guilds will emerge. For this reason, the guild members will gradually be expelled, and quickly the possibilities of becoming a member of alternative guilds are exhausted. This instability and diminishing number of traders who are guild members will lead to weak embargo pressures and decreases in property rights enforcement levels.

In the models of adjustable guild membership, both the tolerance and opportunism variables are distributed. In consequence, the levels of tolerance and opportunism in the guilds will tend to

approach the population mean. In order to examine whether a selection effect could lead to a sorting of opportunism, we therefore estimated an alternative model without cultural adjustment. The results of this model are reported in panel II of Figure 3.

Figure 3 here

As can be seen, this model leads to higher levels of property rights enforcement, in particular when opportunism is low (0.03) and tolerance is fairly high (0.40). A further consequence of the model without cultural adjustment (Figure 3, panel II) is a diminished sensitivity to high levels of tolerance and an increased sensitivity to high levels of opportunism. The reason is that this model quickly leads to a stable situation with the most opportunistic traders excluded from guilds and a majority of traders as permanent guild members. As shown in panel II of Figure 3, the level of property rights enforcement, on average, reached a maximum level of 0.81 (tolerance 0.40) and 0.82 (tolerance 0.50). These levels compare to the levels of between 0.81 and 0.83 obtained in the model with fixed guild membership.

In the model with adjustable guild membership reported in panel I of figure 3, the adjustment rates (α) were normally distributed around the mean value of 0.10 with std. dev. 0.05. According to the results reported in Figure 3, heterogeneous and distributed adjustment rates promote enduring guild membership and stability through selection in the wealth-based adjustment model. A further detailed examination of this issue indicated that an alternative model in which the weights that determined the mean level of guild tolerance and opportunism was based on tenure; the longer the tenure, the stronger the influence on the guild's culture.

Figure 4 here

Since higher opportunism leads to less tenure, the tenure-based adjustment model will internalize the selection effect of the wealth-based adjustment model. For this reason, the rate of adjustment to the weighted average of the guild's opportunism and tolerance becomes an important determinant of guild stability. In order to examine this effect, we set the level of opportunism to an average of 0.20 (std. dev. 0.10) and examined how alternative levels of adjustment and tolerance influenced the emergence of property rights enforcement. A further issue concerned the adjustment rates. According to a number of test runs, identical adjustment rates to a larger extent than heterogeneous adjustment promoted enduring guild membership and stability in the tenure-based adjustment model. For this reason we used identical adjustment rates in the simulations of tenure-based adjustment of guild culture.

As shown in panel I of Figure 4, the tenure-based adjustment model leads to levels of property rights enforcement between 0.80 and 0.84 when tolerance is 0.25 and the adjustment rate is between 0.10 and 0.50. These levels compare with the model with fixed guild membership and the wealth-based model without cultural adjustment. The main difference, however, is that these high levels of property rights enforcement are reached for a relatively high level of opportunism (0.20) and a relatively low level of tolerance (0.25). The virtue of the tenure-based adjustment model, then, is that it can promote the necessary stability and endurance of guilds (as shown on panel II of Figure 4) even when the traders have levels of opportunism and tolerance that appear quite realistic. Remarkably, this requires a positive rate of cultural adjustment. That is to say, the individual guild members adjust to the culture of the guild, which again influences their behavior.

5 Conclusion

If exchange relationships are conceived as repeated interactions, some limited circumstances favour the existence of self-enforcing contracts, based on reputation effects (Sugden 1989, Kreps 1990, Knight 1992, Greif et al. 1994), yet Cooter and Landa (1984), Sened (1997), and others show that reputation effects are inadequate for the emergence of property rights enforcement when the number of traders is sufficiently large. Further, Greif et al. showed that a simple reputation mechanism in a repeated game is insufficient to support the expansion of an adequate level of trade in the Middle Ages. According to Greif et al. an additional institution, the guild, was necessary to help rulers to honour the traders' rights. Our results support and complement the conclusions reached in previous research.

Our main result is that high levels of property rights enforcement can emerge without reputation effects but as a result of the joint effect of guilds' embargo pressures and medium to high levels of price variation. Both conditions were fulfilled in parts of Europe in the Middle Ages. Apart from a minimal requirement that guild membership can be easily verified, no reputation mechanisms are required; our results solely depend on behavioral adjustment. Our model thus provides an explanation of the emergence of property rights enforcement that complements the mechanisms emphasized in previous research.

In view of the cost of gathering information in medieval times, and in more recent times, one of the strengths of the present analyses is to show that even in the absence of information about the causes of fluctuations in trade, guilds could make rulers respond in a way that greatly expanded trade. The requirement is that rulers must develop a robust way to decide whether fluctuations in

trade are caused by embargos, by price variation, or by competition among towns. The omission of considerations of price variation allows Greif et al. to ignore this difficulty.

The increasing price variation in the 13th century is an important historical fact (Bailey 1998, Fischer 1996), and as we have seen in our model, it was high price variation that made uncoordinated embargo pressures from multiple guilds effective. Price variation had the surprising role of eliminating the feedback to rulers that comes from the competition between towns in attracting traders. When the variation in prices is very low, the towns compete to attract traders. For example, those towns with marginally higher sales prices do not have to raise the level of property rights enforcement as much as those towns with slightly lower sales prices. As the locations with high and low prices shift because of the random walk in prices, a steady state is reached with a slight overall increase in the level of property rights enforcement. The effect of the embargo is a loss of trade, and as the ruler experiences this loss of trade, he will increase the level of property rights enforcement. The loss on embargos will not be much larger than the loss of trade from the marginal adjustment of prices and the marginal loss to other towns providing higher property rights enforcement.

Instead, as price variation increases, the feedback to the rulers primarily comes from the loss of trade that happens because of embargos. The increased price variation itself increases the noise in the feedback the ruler receives. As the noise increases the effects of competition between towns is washed out and what remains is the increasingly important loss of trade from embargos. As the price differences increase, an embargo begins to make a huge impact on the ruler's income, and that impact correlates with the level of property rights enforcement.

The effect of increasing the level of price variation is therefore to wash out competing sources of income that confound the correlation between property rights enforcement and income. As the price variation increases further, the embargo pressure must also increase in order to provide clear

feedback to the ruler. Under these conditions, our simulations showed that a regime of very high price variation can lead to the emergence of high and stable levels of property rights enforcement even when opportunistic guild members are tempted to forgo embargos.

In addition to high price variation, the critical requirement in obtaining high levels of property rights enforcement in our model was sufficient stability in guild membership to prevent embargo pressures from becoming ineffective. Such stability is ensured in our tenure-based model when members' adapt to a guild's specific culture. In our model, the guild's only sanction is to expel its members, a sanction that was commonly used (Greif et al. 1994, Landa 1981). The sanction of expulsion, however, raises a problem in that the guild's embargo pressure could be undermined by opportunistic traders. As long as the leak of expelled members is not too big, the guild's embargo pressure remains effective. We have shown that the guild's culture could develop to limit this leak through a selection effect (the wealth-based cultural adjustment model) or an adaptation effect (the tenure-based cultural adjustment model). Ironically, a further effect that helps reduce the leak is that traders truly are opportunistic. They only break an embargo if the probability is high (more than 0.95) that this is to their advantage. Given an adjustable guild culture and the calculation of the gains of breaking an embargo, the guilds in our models were sufficiently stable to make their embargo pressures effective.

The major differences between our results and those obtained by prior research is that we explain the stability of guilds through cultural adjustment and show that high levels of property rights enforcement can emerge even in the absence of coordinated response by multiple guilds. Our results can be viewed as a complement to those of Greif et al., even if they assume that one large guild effectively coordinates its members' response. The advantage of our results lies in showing that high levels of property rights can emerge even if the responses from multiple guilds are not explicitly coordinated. Our simulation also underlines the possibility that the development of well-

enforced property rights in medieval Europe was not entirely the consequence of an endogenous process of institutional development, but also depended on population pressure and other factors leading to price variation.

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Figures

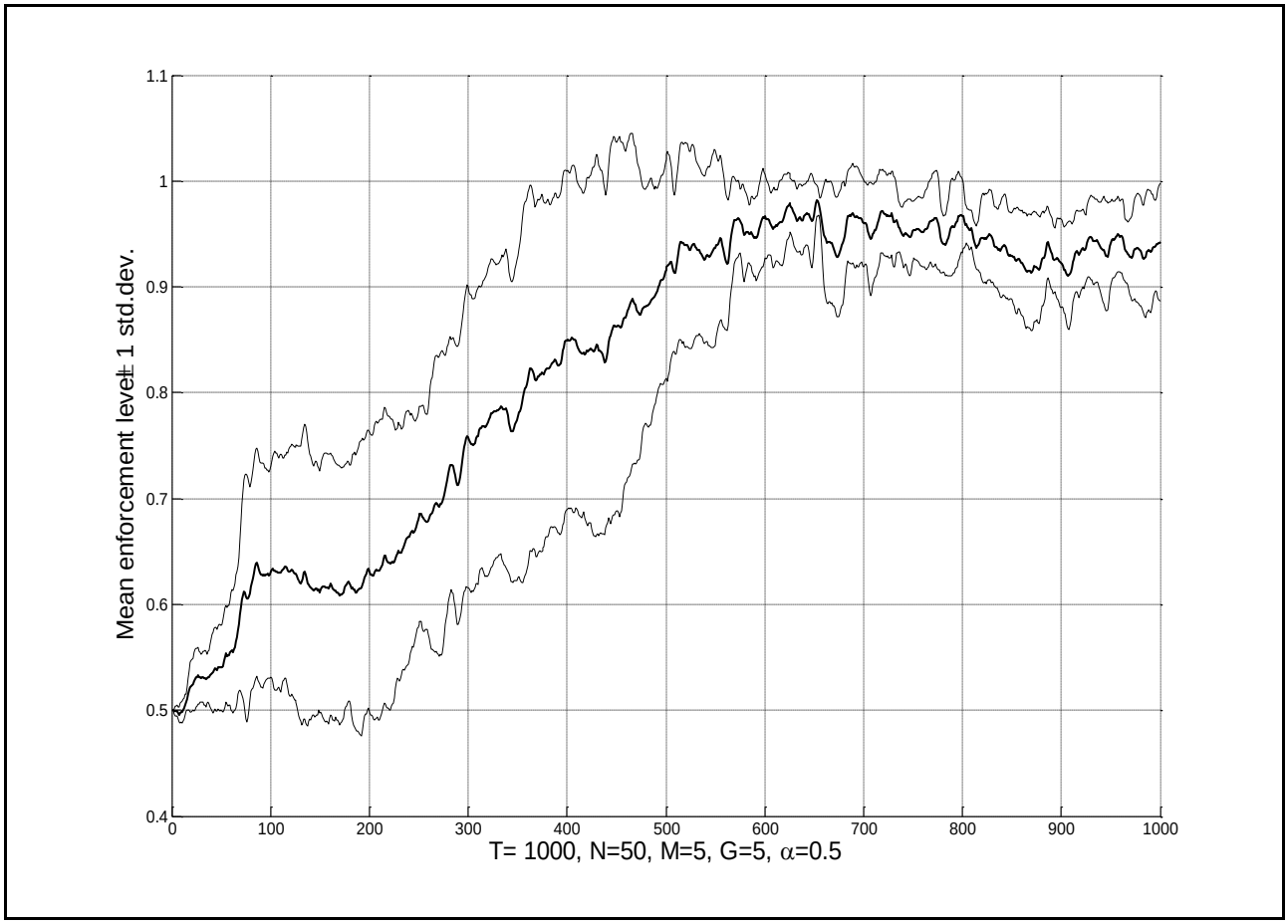

Figure 1: Standard model, adjustable guild membership, medium price variation ±1 std. dev.

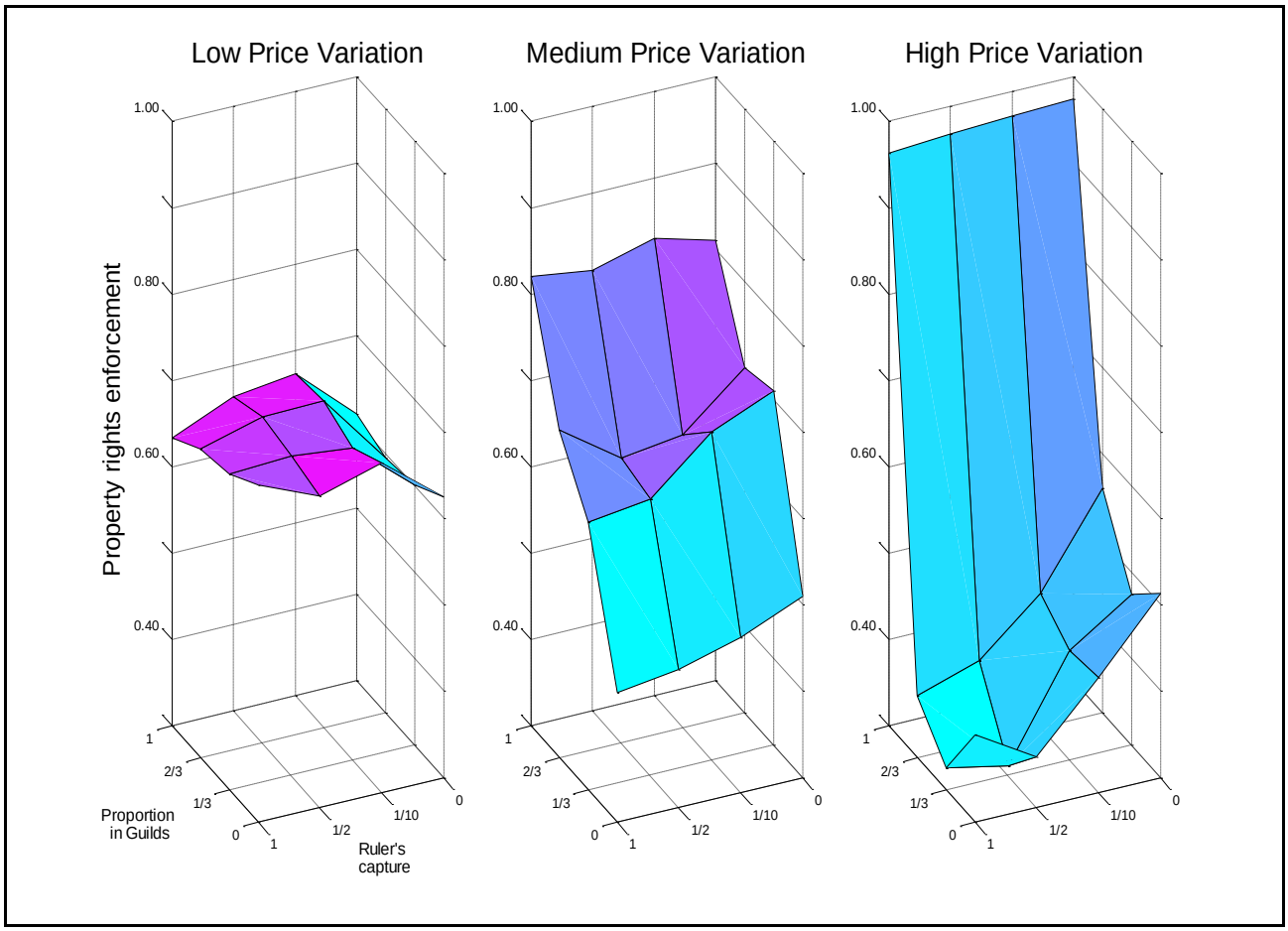

Figure 2: Models of Fixed Guild Membership. Throughout the simulation, 0 of the traders, 1/3 of the traders, 2/3 of the traders, or all traders are members of a guild. The ruler captures nothing, 1/10 of the value of the stolen goods, 1/2 of the value of the stolen goods, or all of the value of the stolen goods. The price-level was set to an average of five. Low price variation is a std. dev. in prices of 1, medium price variation is a std. dev. in prices of 4.5, and high price variation is a std. dev. in prices of 9. The results are based on averages of 30 samples for each of the 48 combinations in the parameter-space. Each sample of T=1000 time-steps, N=50 traders, M=5 rulers, and G=5 goods. Each panel reports the average level of property rights enforcement during the last 10% of the simulation.

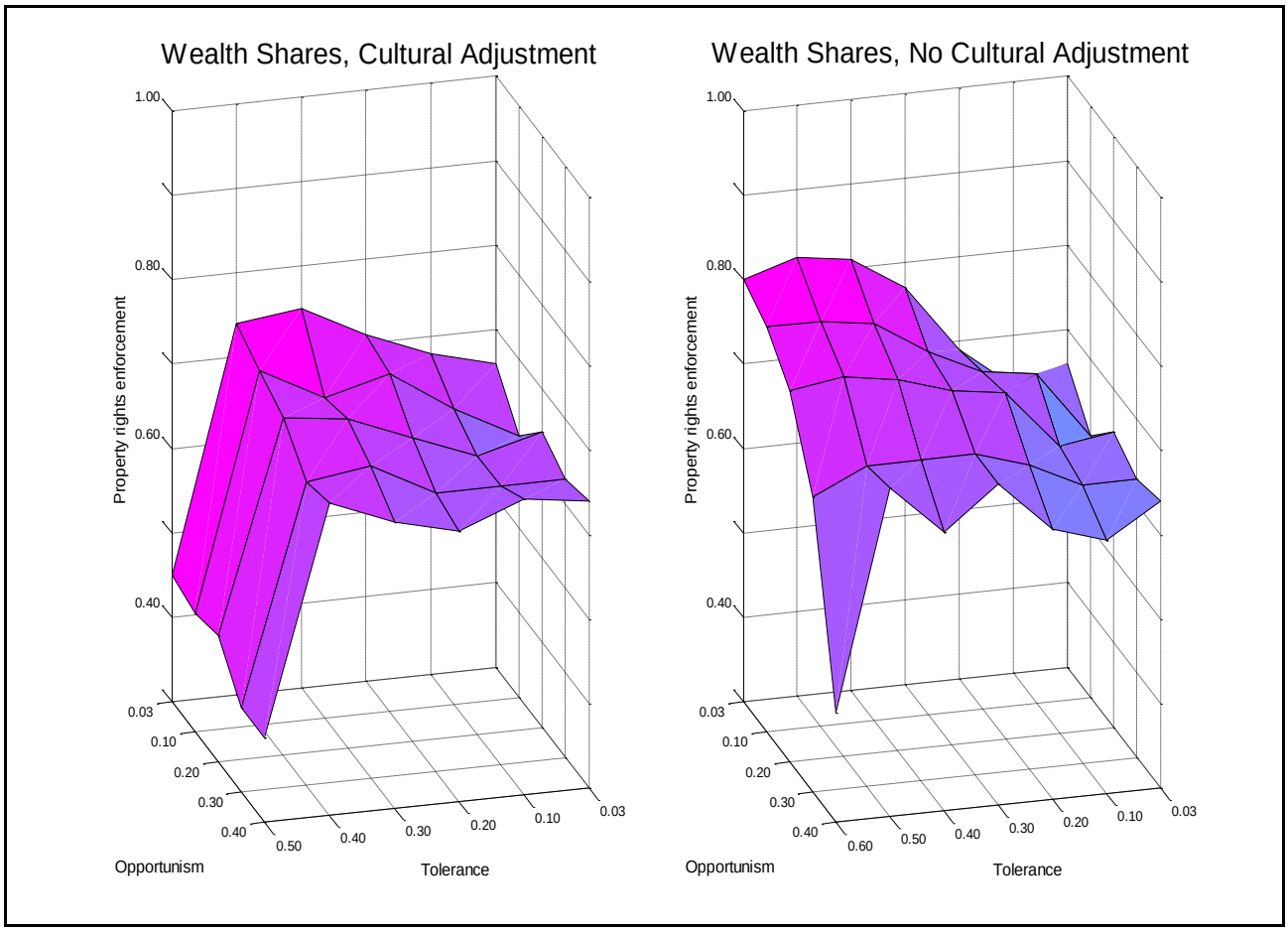

Figure 3: Cultural adjustment model (panel I), average Alpha= 0.10 (normal distribution, std. dev. 0.10). Model without cultural adjustment (panel II), Alpha= 0 for all traders.

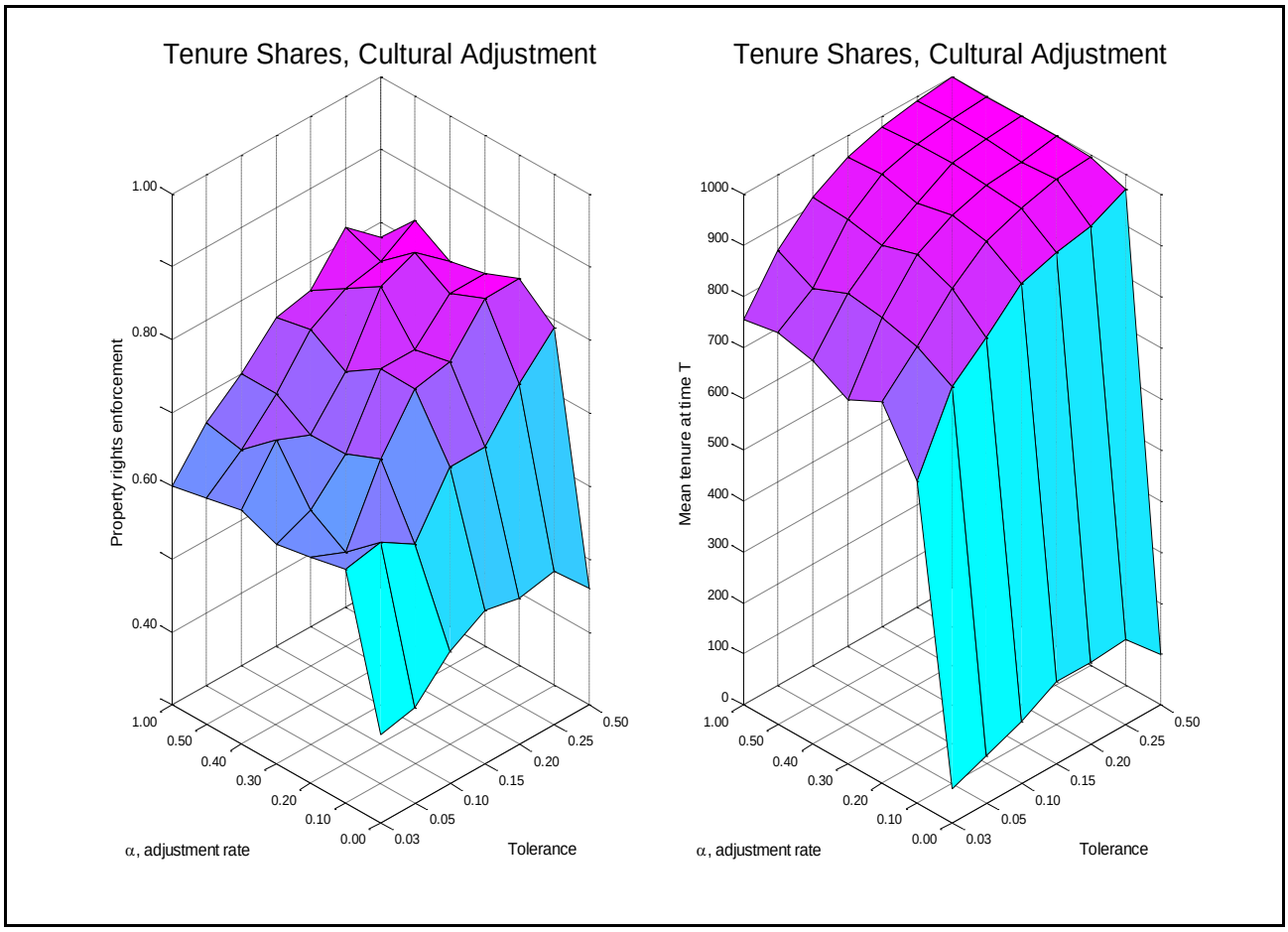

Figure 4: Opportunism is set to 0.20. The adjustment rate of opportunism and tolerance, Alpha, is identical for all traders.

Appendix 1

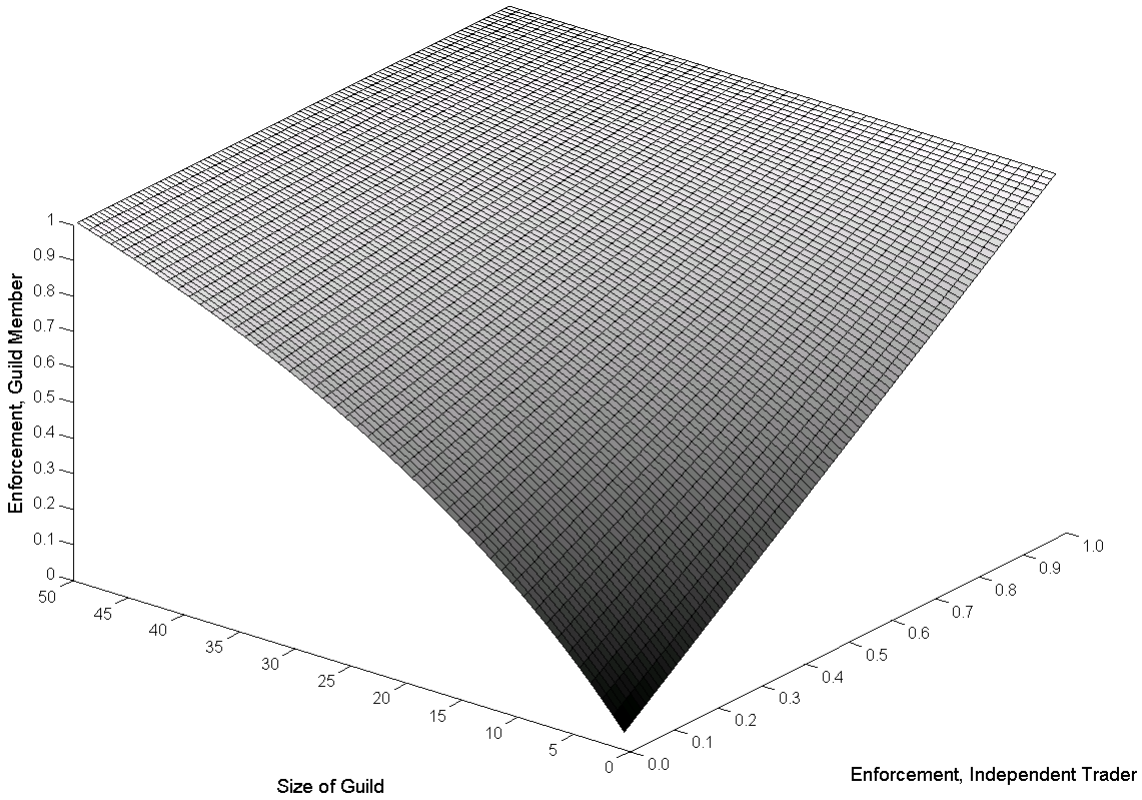

Figure 5: The relation between enforcement for independent traders and guild members