Demand For Contract Enforcement in a Barter Economy

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Abstract

Do greater potential gains from exchange *enhance* or *erode* contracting institutions? In our dynamic exchange model traders have to agree to interact and the reservation value of a tradeable good is determined in the equilibrium, depending, in particular, on the presence of a third party capable of enforcing the contract signed by trading partners. We show that the value created by the enforcement may exist even when contracts are sometimes broken in equilibrium. Larger potential gains from exchange may dampen the demand for enforcing the contracts facilitating exchange: however, for 'high quality' institutions (that oversee the interactions frequently enough) the gains from exchange contribute to a growing willingness to pay for the enforcement.

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1 Introduction

It is a common presumption that the institutions that support exchange have a positive effect on economic prosperity. However, if exchange requires agents to follow contracts, it is not clear whether the converse is true. Do greater potential returns from exchange necessarily imply that private contracts create greater value?

In an exchange economy, voluntary interaction between agents is necessary for the creation of economic value. However, each agent would be better off if she were able to obtain the other's goods without giving up her own. Thus, in principle, potential gains from exchange may or may not be realized. A variety of institutions exist to encourage 'fair exchange': North (1984) and more recently Acemoglu and Johnson (2003) broadly classify them as property-rights institutions, which protect against predation, and as contracting institutions enforcing private agreements. There is an extensive literature on the determinants of effective property rights and, by contrast, contracting institutions have been comparatively neglected.[1]

Our objective is to study the endogenous demand for contract enforcement in an exchange environment. We model a supplier — be it a government or a private firm (or, possibly, even competing firms) — as an entity that offers enforcement services, and traders may obtain them only if it is in their interest to do so.

The demand for an enforcement agency is associated with the value of a tradeable resource. Larger gains from successful exchange generate greater willingness to pay for the assurance that such an exchange will take place. This is similar to the demand for property-rights enforcement: the more one values a house, the more one is ready to pay for its protection. However, there is another effect that alters the value of a *tradeable* good — its value outside of the current interaction. Greater (potential) gains from exchange enhance the future prospects of trading the good, thus weakening the motivation to fulfill current obligations. This effect encourages more agreements to be broken when the gains are larger, which dampens the value of the tradeable and decreases the willingness to pay for a fixed level of protection.

In our model, individuals face *quid-pro-quo* exchange opportunities. We define a *contract* as a pre-agreed specification of behavior, which may be used as a basis for enforcement by a third party.[2] Each agent may independently choose not to fulfill her side of a contract.[3] Following Dixit (2004), we assume a large, anonymous market in

[1] See for example Umbeck (1981), Skaperdas (1992), Moselle and Polak (2001), Grossman (2001), Grossman and Kim (1996), Gonzalez (2007) and Bös and Kolmar (2003). Exceptions include Fafchamps (2002), Dixit (2003b) and most recently, Dhillon and Rigolini (2006) as discussed below.

[2] Thus, unlike the related work of Hoffmann (forthcoming), we abstract from self-enforcement to focus on third-party enforcement.

[3] Contract: A mutual agreement between two or more parties that something shall be done or forborne by one or both esp. such as has legal effects [...] *Oxford English Dictionary (Second Edition, 1989).*

which agents do not meet twice. In such an environment, any exchange agreement will be broken in the absence of enforcement, and the equilibrium value of resources is low as a result. Thus, our benchmark model is one of anarchy in the sense of Hirshleifer (1995), "without effective regulation by either higher authorities or social pressures." Into this environment we introduce a third party that can register contracts, impose a punishment on infractors and reinstate goods to any victims.[4] Detection is imperfect, and – in the eyes of the agents – it occurs randomly, with a certain probability. We refer to this probability as *the quality of institutions*. We establish the conditions under which contract enforcement creates value in equilibrium, and examine how this value is affected by what we call *gains from trade* – an instantaneous enjoyment of the successful interaction with another agent. Perhaps surprisingly, we find that this effect is ambiguous. On the one hand, increased gains from trade directly augment the value of a successfully traded good. On the other hand, the lure to break a given contract strengthens, promoting contract infringement. We show that this temptation dominates the decision calculus if the quality of institutions is low, or if the discount rate is high — in which case the demand for enforcement falls to zero if the gains to trade are sufficiently large. This contrasts with environments in which decentralized norms support cooperative behavior, which rely on a *high* discount factor (such as Kandori (1995)).

Interestingly, in equilibrium, agents who ultimately *break* their contracts may be just as willing to pay for contract enforcement as agents who *follow* the contracts they sign. This is so in spite of the fact that contracting is costlier for infractors, who may be subject to punishment if caught. However, their alternative is not to register their agreements – in which case their partners would not find it optimal to attempt to trade with them either. In effect, the enforcement agency introduces a commitment mechanism that helps individuals assure their partners that the probability of them behaving as traders is the same as the equilibrium fraction of traders in the population – a "stamp of legitimacy." This ability to partially commit increases the value of exchange goods for all individuals and, as a result, both trading behavior and breaches of contract may coexist in equilibrium. The value created by enforcement here differs from the one in Dhillon and Rigolini (2006), where the ex-ante unobserved quality of a single good is the reason for the enforcement institutions to arise: producers implicitly sign the contract promising high-quality goods, and thus the desire to pay for enforcement is not the same across agents.

Dixit (2003b) also studies a prisoner's dilemma among matched agents, assuming that both the gains from trade and the anonymity of interaction increase with the "distance" between traders. As a result, bigger markets are plagued by robbery in the absence of an external enforcer. Third-party enforcement in that model is always

[4] Enforcement-based systems of exchange include formal government, as well as "privately-provided" protection, as surveyed by Dixit (2004) and Greif (2005).

effective, i.e., “any cheating is detected” and it consists of informing potential traders about each others' past behavior for a fixed price. The punishment is then left for the traders to impose, which is limited by the range of the payoffs from their interaction. Besides, the usual presumption[5] is that in any interaction the traders ‘sign a contract’ to cooperate.

We want to leave the decision of which contracts to sign to the agents and study the demand for a ‘primitive’ (but historically relevant, see Greif (2005)) enforcement which consists of re-instating the good to the owner and punishing the cheater. The third party transmits no information and traders almost never meet twice, so the ‘technology’ of enforcement is a-priori unrelated to the gains from exchange, although explicitly introducing the connection between the severity of punishment and the gains provides a useful benchmark in this model (when ‘punishment fits the crime’).

Section 2 describes the economy, and section 3 characterizes the equilibria. Section 4 derives the demand for contract enforcement services, and the discussion and conclusions follow.

2 Economic Environment

2.1 Basic Model

There is a continuum of infinitely-lived, risk-neutral agents who maximize the discounted sum of expected future payoffs using a discount factor $\delta \in (0, 1)$. Each agent holds one unit of an indivisible good, that does not perish until consumed. The good comes in many varieties, and the agent herself does not directly enjoy her possession: however, other agents do.[6] Thus, individuals must interact and obtain the goods of other agents. The model of interaction is open to several interpretations, for instance, the goods could be interpreted as entrepreneurial ideas that require development or financing for their execution, or simply as goods and services to be exchanged. What is important is that agents require the cooperation of other agents to obtain any returns — and that their partners may abscond, retaining both the fruits of interaction and their investable resources.

Matching is random and anonymous. Each matched pair receives an opportunity for a mutually beneficial project as described below. When an agent's good is used, she leaves the market and is replaced by another agent. If after a match an agent retains her good, she is matched anew the following period.

Matches have two stages. In the first stage, the pair may sign a *contract*, specifying actions to be taken by the pair in the second stage. Agents may also write a “null”

[5] The same assumption holds in De Mesquita and Stephenson (2006), where a trader can only select a partner.

[6] This is as in the related matching literature, for example Kiyotaki and Wright (1993).

contract that allows any action to be taken by either trader in the second stage. One agent (randomly assigned with equal probability) may write, sign, and offer a contract to the other, who either signs the contract or abandons the match. Thus, in accordance with the definition of a "contract" – requiring voluntary participation – agents cannot be worse off under the contract in expected terms than if they were to wait until the following period for another match.

In the second stage, each agent chooses one of two actions *trade* or *rob*. If an agent chooses *trade*, her good is used up and her partner receives $G > 0$ units of utility. However, if she chooses *rob*, then she obtains her partner's good and receives utility G herself, provided her partner chose *trade*. If both agents choose *rob*, then each one succeeds in capturing the good of the other with equal probability, giving nothing in return. The winner consumes the good of the loser, retaining her own resources for future transactions. We refer to the parameter G as *potential gains from trade*. We say that a *breach of contract* occurs if there is a discrepancy between the actions specified in the contract and those that are actually taken in the second stage.

Agents view the value of their possession as the expected stream of utility for which they can exchange it in the market. Let V denote the equilibrium value of a good to its holder. The payoff matrix in a given match in this environment is:

		Agent 1	
		Trade	Rob
Agent 2	Trade	G, G	$0, G + \delta V$
	Rob	$G + \delta V, 0$	$(G + \delta V)/2, (G + \delta V)/2.$

Notice that, so long as $V > 0$, this problem has the structure of a prisoner's dilemma. The value of the tradeable, V, depends on the probability γ of meeting a trader in the market place, and both of these values are endogenous. For example, if all agents refuse to sign any contracts, then $\gamma = 0$.

We assume that during each match (within one period), the agents are playing a subgame perfect Nash equilibrium. Hence if a contract is signed by both parties in an equilibrium, the expected payoff to each must be bounded below by δV, the value of waiting until the next period for another partner. This rules out asymmetric contracts prescribing one of the agents to rob and another to trade: no such contracts will be signed in equilibrium. Out of the three types of symmetric contracts (including the 'null' contract which does not prescribe behavior), we will be especially interested in the one that prescribes trade for both partners, i.e., a *trading contract.*

We are looking for stationary subgame perfect Nash equilibria of the infinitely repeated game. For most of what follows the choice of the contract between the agents is simple, given their beliefs about behavior in the second stage. As a result, we limit our definition of equilibrium to profiles of actions at the second stage of each interaction.

Thus, $\gamma \in [0,1]$ is an *equilibrium* if it describes the proportion of agents in the economy who choose to trade in a stationary subgame perfect equilibrium of the infinitely repeated game with random matching.

We restrict attention to pure actions in each period, so we can view γ as the expectation held by any agent that his matched partner is going to trade.[7] Clearly, under both interpretations, if $\gamma \in (0,1)$ is an equilibrium, any agent is indifferent between trading and robbing in every period, whereas if $\gamma = 1$ or $\gamma = 0$ is an equilibrium, then all agents adopt the same pure strategy each period.

Under anarchy, the equilibrium is straightforward to characterize. Let the value of the tradeable good in this case be denoted by V^a. Taking the proportion of traders γ as given, an agent has to choose her best action. If she opts to trade, the payoff is γG. On the other hand, if the agent robs and the partner chooses to trade, she earns G and retains her good for continuation payoff V^a in the following period. Thus, the latter encounter yields the value of $W = G + \delta V^a$. Finally, if both agents simultaneously attempt to rob, she expects to receive $\frac{1}{2}W$, as she has a chance of a half to capture the possession of the other, while retaining her own. In this case, the payoff conditional on the match is $\gamma W + (1-\gamma)\frac{1}{2}W$. Thus,

$$V^a = \max\left\{\gamma G, \gamma W + (1-\gamma)\frac{1}{2}W\right\} \tag{1}$$

It is immediate that V^a is strictly positive for any γ, so that the only equilibrium under anarchy is $\gamma = 0$, and therefore value of the tradeable is $V^a = \frac{G}{2-\delta}$. Although many kinds of contracts could be written in equilibrium, their stipulations are ignored and all matches result in a contest between agents over each other's goods.[8]

2.2 Enforcement Agency

Into this environment we introduce an agency that enforces contracts. The agency endorses contracts that are written in the first stage of a match, before agents have chosen their action either trade or rob. Then, with probability $\omega \in (0,1)$, the second stage of any given match is observed by the agency. If a contract is broken and this is detected, the agency inflicts a cost C upon the defector and reinstates any stolen items to the injured party. We assume that, in the event that *both* partners attempt to rob and this is observed, only the successful robber is punished. The presumption is that it is impossible to verify an unsuccessful robbery attempt (an intent to rob).

[7] Mixed strategies (at each stage) might also be allowed in our environment, see Al-Najjar (2004): the game can be reduced (using stationarity of the environment) to a static one in which (1) agents have only two actions, *trade* and *rob*; (2) the payoff of the agents is V, the value of the tradeable, which depends on the "aggregate" value of γ and the action chosen by this agent; and (3) each agent uses an independent randomization device. We focus on pure actions to simplify the exposition.

[8] Note that resources are still valued in this equilibrium, even though no fair exchange takes place.

Cost C can be thought of as physical punishment, ignominy, or a claim towards a stream of goods to be owned in the future. We analyze two cases. In the first one the protection agency imposes a proportional punishment, $c = \frac{C}{G}$, (or 'punishment fits the crime') and in the second the punishment is independent of the gains from trade and is fixed at C, as punishments may be bounded by cultural norms or technological constraints.[9] [10]

Parameter ω may be interpreted as reflecting limitations in the technology of surveillance and forensics. ω might also depend on the structure of the internal organization of the enforcement agency, which we take as given.[11] As mentioned in the introduction, we call ω the *quality of institutions*, and say that the agency is characterized by a punishment-quality pair. We derive the equilibria under all possible such combinations and determine the economic value generated by each.[12]

In the presence of the enforcement agency, expected payoffs change. Let V^g be the value of her tradeable to an agent who has signed a trading contract. An agent who chooses *trade* and is matched with another who chooses *rob* earns $\omega\delta V^g$ in expectation, as her good is reinstated if the violation (by her partner) is detected. If she meets a fair trader, the payoff is G, as before. Hence, the expected payoff to trading is

$$u\,(\text{trade}) = \gamma G + (1-\gamma)\,\omega\delta V^g \tag{2}$$

The payoff to *rob* is affected as well. If detected, an agent must pay the cost C. Thus, if her partner trades, she earns $W^g \equiv (1-\omega)\,(G+\delta V^g) + \omega\,(-C+\delta V^g)$. If both agents *rob*, the expected payoff to each is:

$$u\,(\text{rob}) = \gamma W^g + (1-\gamma)\left[\frac{1}{2}W^g + \frac{1}{2}\omega\delta V^g\right] \tag{3}$$

Finally,

$$V^g = \max\left\{u\,(\text{trade})\,,u\,(\text{rob})\right\}. \tag{4}$$

[9] Clearly, in practice, punishment may be bounded, as even economic crimes that carry the death penalty are perpetrated.

[10] In the model, (i) punishment is limited, or else set to fit the crime, and (ii) punishment C is neither history-dependent nor modeled as a term of imprisonment. Immediate, history-independent punishments characterize most past cultures and judicial systems, except where slavery was used as a punishment. An early example is the Code of Hammurabi of the 20th Century BC, which punishes theft with a fine – or death if payment is beyond the ability of the perpetrator. See Jastrow (1980). Jewish and Islamic criminal codes are related to the Babylonian codes. As for imprisonment, according to Foucault (1975) in Europe, imprisonment did not begin to replace fines or terms of service as punishment until the 17th Century, and was the lot of few until the early 19th Century, when an elaborate prison system developed. See also Kirchheimer and Rusche (1939).

[11] Equivalently, ω may also be interpreted as the ex-post effectiveness of *guarding* by the enforcement agency. Proposition 2 shows that, provided $\omega > \delta$, there will still be demand for the agency when it guards but does not punish, i.e. when $C = 0$.

[12] Thus, we are deriving the demand for enforcement, taking the *supply of enforcement* (if well-defined) as given. We return to this later.

3 Equilibrium with Enforcement

To understand how the willingness to pay for enforcement is affected by fundamentals, we must first describe the equilibria of the economy, and these appear to depend only the relative punishment, $c = \frac{C}{G}$. Let $\underline{c} \equiv \frac{(\delta - \omega)}{\omega}$, $\bar{c} \equiv \frac{(1-\omega)}{\omega}$.

Proposition 1 *1. Suppose $\delta \leq \frac{1}{2}$. If $c < \underline{c}$, the only equilibrium is $\gamma = 0$. If $c > \bar{c}$, the only equilibrium is $\gamma = 1$. Finally, if $c \in [\underline{c}, \bar{c}]$, then there are three equilibria: two on the boundaries, $\gamma = 0$, $\gamma = 1$ and one in the interior, γ_L.*

2. Suppose $\delta > \frac{1}{2}$. There exists $\underline{\underline{c}} < \underline{c}$ satisfying the following. If $c < \underline{\underline{c}}$, the only equilibrium is $\gamma = 0$. If $c > \bar{c}$, the only equilibrium is $\gamma = 1$. If $c \in [\underline{\underline{c}}, \underline{c})$, then there are three equilibria, a corner one, $\gamma = 0$, and two *interior ones, γ_L and γ_H, where $\gamma_L < \gamma_H < 1$. Finally, if $c \in [\underline{c}, \bar{c}]$ then there are three equilibria: two on the boundaries, $\gamma = 0$, $\gamma = 1$ and one in the interior, γ_L.*

Corollary 1 *If punishment is proportional to the gains from trade, an increase in the gains from trade has no effect on the equilibrium value of γ.*

Equilibrium structure is illustrated in Figure 1. If punishment is small relative to the gains, *rob* remains a dominant strategy as under anarchy and there is no trade in equilibrium. If it is large relative to the gains, then *trade* is a dominant strategy and there are no breaches of contract. For intermediate values, the equilibrium with no trade coexists with two equilibria with trade and, depending on parameters, either one or both of them will feature breaches of contract as well as trade in equilibrium. The reason is that there is a complementarity between the actions of potential trading partners. This complementarity is inherently dynamic, as it hinges on balancing the threat of current punishment against the value of future interaction, the value of which depends positively on γ. Interestingly, the existence of multiple equilibria is consistent with the empirical findings of Glaeser et al. (1996) that crime rates appear to vary significantly more than can be accounted for by observables.

Multiplicity of equilibria can be avoided, however, if we rely on a refinement. The lower equilibrium, γ_L, is unstable in the sense suggested by DeMichelis and Germano (2000). By contrast, the upper equilibrium, γ_H, is stable in this sense, and is also increasing in the normalized punishment c:

Lemma 1 *Assume $\delta > 1/2$ and $c \in \left(\underline{\underline{c}}, \underline{c}\right)$. Then, γ_H is increasing in c.*

From now on we focus on stable non-zero equilibria, $\gamma = \gamma_H$ or $\gamma = 1$, if they exist.

Now we can turn to the analysis of demand for contract enforcement.

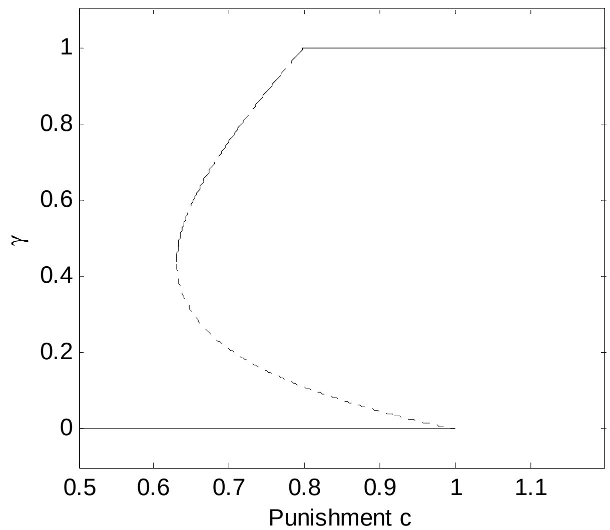

Figure 1: Equilibrium with $\delta > \frac{1}{2}$. Note that γ_L is depicted as a dotted line and γ_H is depicted as a dashed line.

Definition 1 *The* equilibrium demand for enforcement D^* *is the most that an agent would be willing to pay for the third-party agency to endorse a contract.*

D^* represents the highest economic value created by endorsing contracts, provided this value is positive. Naturally, this demand depends on the effectiveness of contract enforcement, or the proportion γ of traders in the economy. This proportion, of course, is an equilibrium variable that depends on the fundamentals and the severity of punishment. So, we let D^* be the difference, $D(\gamma_H)$, between signing the contract that will subsequently be enforced (thus expecting a partner to be a fair trader with probability γ_H) and a sure fight between the two (in case neither signs the contract). How is this difference determined?

If agents agree to a trading contract and $\gamma > 0$ in equilibrium, the payoff is the equilibrium value of the tradeable good, $V^g = \gamma G + (1-\gamma)\,\omega\delta V^g$. The alternative is to agree on a contest, in which the value of the good is reduced to $1/2\,(G + \delta V^g)$, this decision is just about current period: next time around the value of the good is the highest attainable given the equilibrium played. Note this presumes that next period, if an agent is still in the possession of the good, he has a chance to write a contract and be trusted as any other trader, no matter what he did in the current period, i.e., the value of the tradeable is determined solely by 'the market conditions', i.e., the equilibrium played.[13] Thus,

$$D(\gamma) \equiv V^g(\gamma) - 1/2\left(G + \delta V^g(\gamma)\right) \tag{5}$$

If parameters are such that $\gamma > 0$ is never an equilibrium, or that $\gamma > 0$ is an equilibrium but there are no gains to contract endorsement, $D \leq 0$, then $D^* = 0$. Interestingly, $D \geq 0$ is equivalent to $V^g(\gamma) \geq V^a = \frac{G}{2-\delta}$, so that the agents' willingness to pay for contract enforcement is positive only if the value of the tradeable under enforced contracts is above that of the anarchy.[14] For that to be the case, traders have to be assured that there is a good enough chance to meet another trader, i.e., a partner who does not break contracts, so the induced equilibrium γ has to be high enough.

Note that, if $D^* > 0$, then *all* agents write trading contracts in equilibrium, even if $\gamma < 1$. Hence, breaches of contracts can occur on the equilibrium path. Enforcement benefits both agents who follow contracts and those who break them. Although they run the risk of punishment if caught, infringers enjoy being surrounded by traders whom they can defraud. In order to lure potential victims into a transaction, one has to agree to the contract – which serves as a costly commitment mechanism, since one agrees to pay ones dues if caught. Signing such a contract is worthwhile for those intending to rob, if they expect their partners to trade with high enough probability, which, in turn, depends on technology of enforcement and gains from trade.

4 Properties of the Demand for Enforcement

Lemma 2 *The* equilibrium demand for enforcement D^* *is strictly positive if and only if* c *is larger than a threshold* c^D*, where* $c^D \leq \underline{c}$*. Moreover, if* $\delta > \frac{1}{2}$*, then* $c^D < \underline{c}$*.*

Recall that, if agents are patient, breaches of contract may occur in equilibrium. Lemma 2 shows that the demand may be positive even when enforcement is thus imperfect, for a broad range of parameters.

Now we can start answering the question posed at the very beginning. Provided the punishment fits the crime, yes, the relationship between the gains from trade and demand for contract enforcement is positive.

[13] Again, this is consistent with the assumption that the agents have no chance of meeting twice and the agency is not keeping track of personal histories, thus the value it creates stems solely from its unilateral ability to impose punishments. Thus, this agency is different from the Dixit (2003a)'s "Info" and from Calvert (1998)'s "central clearinghouse of information."

[14] So, alternatively, we could have assumed that agents have a choice between two locations, one anarchic and the other with enforced trading contracts, defining D^* as the difference in payoffs between locations.

Lemma 3 *Suppose the enforcement agency can impose a proportional punishment,* $c = \frac{C}{G}$. *If an equilibrium with contracting exists, then* D^* *is increasing in the gains from trade* G.

In this case, by corollary 1, the fraction of traders on the market γ is constant in G. As potential gains from trade increase, value of the tradeable under enforced trading contracts increases proportionally and, as a result, the demand is increasing in the gains from trade.

By contrast, if the punishment does *not* grow proportionally with the crime, larger gains from trade lead to a decrease in the proportion of traders on the market by lemma 1. As a result, the effect of the gains, G, on demand, D^*, is not necessarily positive.

Proposition 2 *Suppose punishment is constant, i.e., independent of* G. *Then, if an equilibrium with contracting exists,* $D^*(G)$ *increases with* G *if* $\omega > \delta$; *stays positive for any* G, *if* $\delta \geq \omega > \underline{\omega}$ *and* $\delta < \bar{\delta}$.

Otherwise, there exists $\bar{G} > 0$ *so that* $D^*(G) = 0$ *for all* $G \geq \bar{G}$.

There are two effects that stem from an increase in gains from trade. The direct effect is to boost the value of the tradeable good, holding the equilibrium fraction of fair traders constant. However, there is also an indirect effect: the equilibrium fraction of traders decreases. This lowers the equilibrium value of goods, and decreases the willingness to pay for contract enforcement. If the first effect dominates, the demand for enforcement increases with gains from trade for all possible values of G. Otherwise, the demand for contract enforcement will decrease to zero for large enough values of G. See Figure 2 for an illustration.

For the direct effect to dominate, i.e., for the relative value of a tradeable to increase in potential gains from trade, the equilibrium fraction of traders can not decrease too fast with G. This can happen if a deterrent to breaking the contracts is strong enough. As the potential gain G grows, the *proportional* punishment, c falls. Thus, the direct effect will dominate only if parameters are such that some traders exist in equilibrium, even when the punishment c is negligibly small. This occurs precisely when δ is low. If a violation of a contract is detected, robbers incur the punishment along with the cost of waiting until another opportunity to interact arises in the future. If δ is low then this delay is more a severe hit, as the future is heavily discounted. In this case the enforcement agency can enjoy a growing willingness to pay for its services by more prosperous traders. Otherwise, the lower boundary on punishments that can support trading in equilibrium increases with G, and so demand for enforcement eventually drops to zero. Thus, "low quality" institutions in patient societies require more severe punishments when potential gains from trade are large, if there is to be an economic basis for their existence.

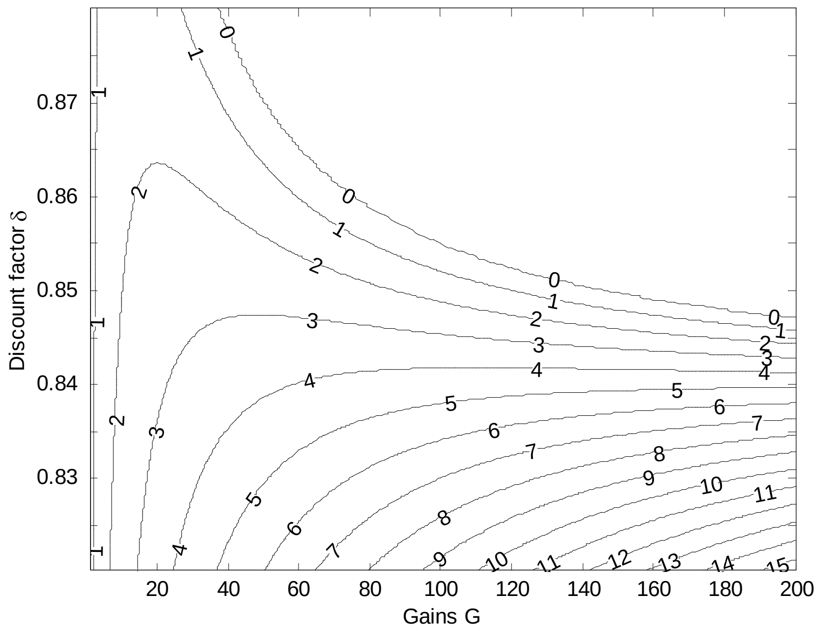

Figure 2: Demand D^* contour plot. It is increasing in G for lower values of δ, whereas for larger values of δ (above about 0.844) D^* eventually drops to zero.

It is worth remembering that the above applies to agents who break their contracts as much as it does to agents who follow them. D^* is also the value of the "stamp of legitimacy" that agents who ultimately break their contracts receive in equilibrium.

How does D^* vary with the other parameters – the quality of institutions and the 'patience' of the traders, or the frequency of their interactions?

Proposition 3 *The demand for enforcement D^* increases with the quality of institutions ω, and falls with the discount factor δ.*

While the first result may seem intuitive, the second might be less so. Recall that a lower discount factor acts as a higher effective punishment in this environment, because delayed consumption is valued correspondingly less. Thus, the equilibrium fraction of fair traders, or the effectiveness of enforcement, rises as the discount factor drops, increasing the willingness to pay for the agency that is capable of deterring an observed infractor from consuming for one period. In an alternative environment in which punishments involve partial or complete banishment from future trading opportunities, (that can be, say, imposed by all the traders), a low discount factor restricts the severity of punishment that a community can impose upon deviators and, consequently, the level of cooperation that will be achieved. By contrast, when the punishment is partly exogenous and swift, we find that it *enhances* the creation of value by an enforcement agency.

5 Discussion

5.1 Extensions

We do not pursue a detailed examination of the potentially interesting interaction between social pressures and a central authority. The effectiveness of 'decentralized punishments' in a repeated interaction framework (mentioned in the previous section) depends crucially on the way information is shared among the players. Decentralized norms could, under certain circumstances, serve as a contract enforcement device in an otherwise anarchic environment, say, as in Kandori (1995). In this case, agents are required to display a summary of their past behavior before a new encounter, so that there is a need for a truthful "book-keeping" agency, i.e., another possible third party; besides punishments have to be coordinated. Calvert (1998) explicitly introduces a centralizing institution (clearinghouse of information) to keep track of individual reports about partner's actions. In one of the equilibria, sufficiently patient players use the clearinghouse to sustain cooperation. One could introduce the choice of signing the contracts into that model and ask the same question: what is the willingness to pay for the 'informational enforcement', bearing in mind that the punishment (say, tit-for-tat strategy in prisoner's dilemma) is limited to be a function of payoffs based on an exchange interaction of agents. Fafchamps (2002) studies the factors that affect the emergence of such "relational contracting." Our paper focuses on environments in which such information is difficult to accumulate or transmit, so that social norms of this kind are weak or ineffective. Remarkably, the case study of Fafchamps and Minten (2001) and the survey of Fafchamps (2002) suggest that this may be the case even in markets in which the participants are *not* frequently renewed.

To focus on contract enforcement institutions, we have made certain assumptions regarding manner in which the agents, and the enforcement agency, interact. It is worth discussing what might happen if we were to depart from some of these assumptions.

First, our punishment setup involves an element of guarding, since stolen items are reinstated to their initial owners. An alternative would be to assume that the agency is unable to reinstate goods: instead, it obliges the thief to give her good to the victim. Note in that case the punishment no longer involves delayed consumption. The structure of the equilibria does not change in that case, although more severe punishment is needed to induce trading behavior.

Second, our model assumes the existence of *property rights*, in the sense that all agreements between private agents are reached voluntarily, even if these agreements are not necessarily followed in equilibrium. If property rights do not exist, however, it may be that agents can be *coerced* into signing enforceable documents. In this case, asymmetric deals of the form $<$*trade*, *rob*$>$ might not be ruled out and, in the presence of an enforcement agency, all agents would want to impose such a relationship upon their partners.[15] The likely winner of such a contest would be willing to pay the enforcement agency for its services: however, in equilibrium, there might no longer be any *exchange*, extortion ruling the marketplace. Interestingly, this is consistent with the empirical findings of Acemoglu and Johnson (2003) that contracting institutions do not appear to function in the absence of property rights institutions.

Third, we have assumed that the third party is not *corrupt*, in the sense that it does not collude with the agents who break their contracts. Assume instead that, when caught robbing, agents may "bribe" the enforcement agency in exchange for not being punished. In the working paper version,[16] we show that if the enforcers can extract all that an infractor is willing to pay to avoid the punishment and reinstatement of the good, the structure of the equilibria remains the same.

Finally, we have so far assumed that an enforcement agency finds it profitable to operate, and it is worth asking whether our results hold at least under standard industry structures for the provision of enforcement. Suppose that there is a constant variable cost per contract that an agency certifies. If there is a unique supplier of such services, as is often the case (at least for a given geographic region), the price charged per-contract is fully determined by the willingness to pay we describe. So long as demand exceeds the cost, this price will be non-negative, and the monopolist may operate profitably. In the case of competing providers, the price would be bid down to the cost so, once again, the condition that demand exceeds the cost is necessary and sufficient for providers to earn non-negative profits. Although the cost increases the minimum punishment necessary for enforcement to be provided, it does not affect the structure of demand, so that the results of Section 4 continue to hold.

5.2 Concluding Remarks

This paper develops a model of contracting and exchange, in which agents' interactions are subject to a participation constraint. Agents choose whether to notarize their contracts in order to commit themselves to trade, even though they may decide to break their promises later. We then use the model to ask whether the presence of potential gains from trade may generate an economic basis for contract enforcement

[15] Piccione and Rubinstein (2007) offer an insightful comparison of the allocations arising in the 'jungle', where agents differ by their ability to extract resources (as well as consume) with the competitive general equilibrium allocations.

[16] Rubinchik and Samaniego (2006).

institutions. For those of high quality the answer is positive: enforcement appears to be valuable, even though, as we assumed, 'fighting' (that prevails under anarchy, i.e., in the absence of the third-party enforcement) does not directly consume any resources. Perhaps surprisingly, larger gains from trade do not necessarily contribute to the economic success of contracting institutions. In particular, the demand for "low quality"institutions decreases in the potential gains from trade. Although these gains increase the benefit to the interacting parties when contracts are followed, it also increases the equilibrium rate of contract violations, and this second effect may dominate for large enough gains from trade unless the severity of punishment is increased in tandem.

An independent question concerns the mechanisms whereby contracting institutions do arise, and we do not address it. Thus, our approach is in the spirit of Stigler (1992), who argues that, under a strong interpretation of the Coase (1960) theorem, if there is value to be created by the provision of a certain service, then economic incentives would lead some arrangement to arise that provides it, be it state-based or otherwise. The willingness to pay for the services can then be taken as an indicator of success (if not to say legitimacy of the provider,[17] as in Nozick (1974)) and therefore it is an important factor contributing to the emergence and persistence of the governments providing enforcement throughout the history.

A Appendix

A.1 The equilibria

Proof of Proposition 1. By lemma 4 it suffices to analyze roots of a function $F(\gamma, c)$ for any fixed c, and its signs at the boundaries, to derive equilibria of the model, where F is essentially the difference between the value of perpetual trade and perpetual theft conditional on γ and c. If $c \geq \underline{c} \equiv \frac{(\delta-\omega)}{\omega}$ then we show that $F(1, c) \geq 0$, so $\gamma = 1$ is an equilibrium; if $c \leq \bar{c} \equiv \frac{(1-\omega)}{\omega}$ then $F(0, c) \leq 0$, so $\gamma = 0$ is an equilibrium. Also if $c \geq \bar{c}$, then $F(\gamma, c) \geq 0$ for any $\gamma \in [0, 1]$, so the *only* equilibrium is $\gamma = 1$. By lemma 5, if $\delta \leq 1/2$ then for all $c < \underline{c}$, the unique equilibrium is $\gamma = 0$ and if $\delta > 1/2$ then there is $\underline{\underline{c}} < \underline{c}$ such that for all $c < \underline{\underline{c}}$, $\gamma = 0$ is the only equilibrium. Finally, lemma 6 implies that if $\delta > 1/2$, there are additional two equilibria, γ_L, γ_H in the interior of the unit interval if $\underline{\underline{c}} < c < \underline{c}$. ■

Lemma 4 *The set of equilibria* γ *of the model with enforcement consists of*

[17] Interestingly, by agreeing to buy the service, individuals have to give up — in addition to some resources — also some of their rights, i.e., they are subject to punishment if caught breaking a contract they signed.

1. *positive roots of polynomial*

$$F(\gamma,c) = \gamma^2 a_F(c) + \gamma b_F(c) + k_F(c), \tag{6}$$
$$k_F(c) = (c\omega - (1-\omega))(1-\delta\omega)$$
$$b_F(c) = (1+\omega)(1-\delta) + c\omega > 0$$
$$a_F(c) = \delta\left(c\omega^2 - (1-\omega^2)\right)$$

2. *unity, if* $F(1,c) \geq 0$,

3. *zero, if* $F(0,c) \leq 0$.

Proof. >From specification of payoffs (2) we can calculate the value of the good, $V_t^g(\gamma;G)$, held by an individual trading every period, and, similarly, the value for a perpetual robber, $V_r^g(\gamma;C,G)$,

$$V_t^g(\gamma;G) = \frac{\gamma G}{1-\delta(1-\gamma)\omega} \tag{7}$$
$$V_r^g(\gamma;C,G) = \frac{(\gamma+1)((1-\omega)G - C\omega)}{\delta(1-\omega)(1-\gamma)+2(1-\delta)}, \tag{8}$$

In a stationary equilibrium, the value of the tradeable is independent of time, so if an action is optimal in a given period, it is optimal forever after. Then only three scenarios are possible. Either everyone trades, so $V^g = V_t^g(1;G)$ and $V_t^g(1;G) > V_r^g(1;C,G)$; or everyone robs, $V^g = V_r^g(0;C,G)$ and $V_t^g(0;G) < V_r^g(0;C,G)$, or, alternatively, anyone is indifferent between robbing or trading: $V_t^g(\gamma;G) = V_r^g(\gamma;C,G)$ for some $\gamma \in [0,1]$.

Let

$$F(\gamma,c) = \kappa(\gamma)\,G\left[V_t^g(\gamma;1) - V_r^g(\gamma;c,1)\right]; \tag{9}$$
$$\kappa(\gamma) \equiv (\delta(1-\omega)(1-\gamma) + 2(1-\delta))(1-\delta\omega(1-\gamma)).$$

Note that $\kappa > 0$, so the sign of $F(\gamma,c)$ coincides with the sign of the difference $V_t^g(\gamma;G) - V_r^g(\gamma;C,G)$, and $F(\gamma,c)$ can be represented as (6). ■

Lemma 5 *If* $\delta \leq 1/2$ *and* $c < \underline{c}$, *then* $F(\gamma,c) \leq 0$ *for any* $\gamma \in [0,1]$. *If* $\delta > 1/2$ *then there is* $\underline{\underline{c}} < \underline{c}$ *such that for all* $c < \underline{\underline{c}}$ *the same conclusion is true.*

Proof. There are two possible cases that can lead the polynomial $F(\gamma,c)$ to be negative for all $\gamma \in [0,1]$. First, if it has no (real) roots and is everywhere negative and second, if both roots are above unity and $F(1,c) < 0$.

If $a_F(c) < 0$, so that $c < \frac{1-\omega^2}{\omega^2}$ (which is true if $c < \underline{c}$), F is maximized at

$$\gamma^* = \frac{1}{2} \frac{(1+\omega)(1-\delta) + c\omega}{(1-\omega^2 - c\omega^2)\delta} \tag{10}$$

In the second case γ^* has to be above 1, which happens if $c > c^*$,

$$c^* \equiv \frac{2\delta(1-\omega) - (1-\delta)}{2\delta\omega + 1} \frac{\omega+1}{\omega} \tag{11}$$

but if $\delta \leq 1/2$ then $c^* \leq \underline{c}$, so $c \in [c^*, \underline{c}]$ implies $\gamma^* \geq 1$, so $F(\gamma, c) \leq F(1, c) < 0$ for any $\gamma \in [0,1]$. Next we show that this is also true if $c < c^*$. Consider $c = c^*$. As $c^* < \underline{c}$, and $\gamma^* = 1$, it implies $F(\gamma^*, c^*) < 0$. As γ^* is the maximand of F, it follows that $F(\gamma, c^*) < 0$ for any γ. But F increases in c. Therefore, for any γ, $F(\gamma, c) < 0$ if $c < c^*$, thus the first part of the statement follows.

If $\delta > 1/2$ then $c^* > \underline{c}$, therefore, for $c < \underline{c} < c^*$ we have (1) $F(1,c) < 0$; (2) $\gamma^* < 1$. Moreover, if $c < \tilde{c} \equiv \omega^{-1}(\omega+1)(\delta-1)$, then $b_F(c)$ is negative and so are the other coefficients, $a_F(c)$ and $k_F(c)$, which implies F has only negative γ roots.

To verify the second claim it is then sufficient to show that there exists $\underline{\underline{c}} > \tilde{c}$, such that for c between $\tilde{c}$ and $\underline{\underline{c}}$, $F(\gamma, c)$ is negative on the unit interval. The parabola $F(\gamma, c)$ can cross zero twice if the discriminant

$$H(c, \phi) \equiv b_F^2(c) - 4a_F(c)\,k_F(c) \tag{12}$$

is positive. $H(c; \phi)$ is quadratic in c:

$$H(c, \phi) = c^2 a_H + c b_H + k_H, \tag{13}$$

where $a_H > 0, b_H > 0$. This implies that the extremum, $\hat{c}$, of this parabola (H) is negative, therefore so is one of the real roots, if exists. H is negative between those roots and it is positive otherwise. Notice also that $\tilde{c}$ lies between the roots, as $H(\tilde{c}, \phi) < 0$. This implies that the upper root of H, which we will denote by $\underline{\underline{c}}$, is strictly above $\tilde{c}$. H is negative between $\tilde{c}$ and $\underline{\underline{c}}$, which implies F has no real roots, and is negative for any γ. The result follows.

Notice also that H is strictly increasing for any $c \geq \underline{\underline{c}}$. Thus,

$$H(\underline{c}, \phi) = G^2 (2\delta - 1)^2 (\delta\omega - 1)^2 > 0 = H\left(\underline{\underline{c}}, \phi\right) \tag{14}$$

implies $\underline{c} > \underline{\underline{c}}$. ■

Remark 1 *Since $a_H > 0, b_H > 0$, the upper root of H is positive, $\underline{\underline{c}} > 0$, iff $k_H < 0$, which is true whenever $\delta > \delta_L$, where δ_L is the lower root of the quadratic polynomial*

$$\begin{aligned} P(\delta) = {} & \omega + 1 + \delta\left(6\omega - 4\omega^2 - 6\right) \\ & + \delta^2\left(5\omega - 8\omega^2 + 4\omega^3 + 1\right) \end{aligned} \tag{15}$$

It is easy to check that $\delta_L \in (0,1)$, provided $\omega < 1$, as $P(1) < 0$ and $P(0) > 0$.

Lemma 6 *Assume that $\delta > 1/2$ and $c \in \left(\underline{\underline{c}}, \underline{c}\right)$. Then F has two roots, $0 < \gamma_L < \gamma_H < 1$.*

Proof. For any fixed c, the two roots of the polynomial $F(\gamma, c)$, are

$$\gamma_L \equiv \frac{-b_F(c) + \sqrt{H(c,\phi)}}{2a_F(c)}, \gamma_H \equiv \frac{-b_F(c) - \sqrt{H(c,\phi)}}{2a_F(c)} \tag{16}$$

where $H(c,\phi)$ is as defined in (12). Condition $c > \underline{\underline{c}}$ assures that $H(c,\phi)$ is strictly positive. Therefore γ_L, γ_H are real. As $a_F < 0$ for $c < \bar{c}$ and $k_F < 0$, the roots are strictly positive.

Since $\delta > 1/2$, $c^* > \underline{c}$, thus any $c < \underline{c}$is also below c^*, which implies that the maximand of F, γ^*, is less than one. Moreover, as $c < \underline{c}$, $F(1,c) < 0$, this, along with the fact that $a_F(c) < 0$ and that the discriminant H is positive guarantees that $\gamma_H(c) < 1$. ■

Proof of Lemma 1. By lemma 4, it is sufficient to show that the upper root of polynomial F is increasing in c, which is well-defined in the view of the the assumptions and by lemma 6. First, $\frac{\partial F(\gamma,c)}{\partial c} = \omega(1-\delta\omega) + \gamma\omega + \gamma^2\delta\omega^2 > 0$. Next, $\frac{\partial F(\gamma,c)}{\partial \gamma}|_{\gamma=\gamma_H} = -\sqrt{H_F}$, where $H_F = b_F^2 - 4a_F k_F > 0$. The result then follows by the implicit function theorem. ■

A.2 Determinants of the Demand for Enforcement

Proof of Lemmas 2 and 3. In the environment with endogenous contracts, if agents agree to a trading contract, then the value of the tradeable should be equal to $V_t^g(\gamma; G) = \frac{\gamma G}{1-\delta(1-\gamma)\omega}$, (though even after signing the contract if $\gamma < 1$ each one is indifferent between robbing and trading). Then, using definition of D, equation (5)

$$D(\gamma, G) = \frac{1}{2}\frac{2\gamma - \gamma\delta + \delta\omega - \gamma\delta\omega - 1}{(1-\delta\omega(1-\gamma))}G$$

is positive if

$$\gamma > \underline{\gamma} \equiv \frac{1-\delta\omega}{2-\delta\omega-\delta}. \tag{17}$$

In this case, D is also increasing in G (for a fixed γ). Lemma 3 then follows from corollary 1.

Lastly, to finish the proof of lemma 2, we have to demonstrate that condition $\gamma > \underline{\gamma}$ is equivalent to requiring $c > c^D$. As $D^*(G) = D(\gamma_H, G)$, so we focus on γ_H, the case $\delta < 1/2$ trivially reduces to requiring $c > \underline{c}$, when $\gamma = 1$ is an equilibrium and therefore, condition (17) holds. So, in this case let $c^D = \underline{c}$. Next, for the case $\delta > 1/2$, notice that $\underline{\gamma}$ is not a function of c and γ_H increases in c by lemma 1. Also,

$\gamma_H(\underline{c}) = 1 \geq \underline{\gamma}$. Two cases are possible. First, if $\gamma_H\left(\underline{\underline{c}}\right) < \underline{\gamma}$, then let c^D be implicitly defined by $\gamma_H\left(c^D\right) = \underline{\gamma}$, the existence of which is assured by the intermediate value theorem (besides, c^D is unique by strict monotonicity of γ_H in c). Second, if $\gamma_H\left(\underline{\underline{c}}\right) > \underline{\gamma}$, then let $c^D = \underline{\underline{c}}$. ∎

Proof of proposition 2. Let us start with two simple cases. If $\omega > \delta$ then $\underline{c} < 0$, so for any $c > 0$ $\gamma = 1$ is an equilibrium. Then, no matter how high is G, $\underline{c}$ stays negative and the demand for enforcement is proportional to G, as $D(\gamma, G) = \frac{1}{2}(1-\delta)G$, so the conclusion follows. Second, if $\omega < \delta < 1/2$, we have $\underline{c} = \frac{G(\delta-\omega)}{\omega} > 0$. Then as G increases, any $c = \frac{C}{G} > 0$ will fall below $\underline{c}$, leaving the only equilibrium $\gamma = 0$, implying $D^* = 0$.

Now consider the rest of the cases: $\omega < \delta$, $\delta > 1/2$. It is without loss of generality to assume $c < \underline{c}$, as if it is not, for G big enough it is. Also, the case $c < \underline{\underline{c}}$ is trivial, as there is no equilibrium with $\gamma > 0$ in that range, so no demand for enforcement exists. Start with some $G > 0$ and $c \in \left[\max\left\{\underline{\underline{c}}, 0\right\}, \underline{c}\right]$ at which the demand for enforcement is strictly positive, $D(\gamma_H, G) > 0$. As G increases two scenarios are possible. First, if $\underline{\underline{c}} > 0$, then for G large enough, c falls below $\underline{\underline{c}}$, which leaves the only sustainable equilibrium, $\gamma = 0$, so $D^* = 0$. Second, in the complementary case, $\underline{\underline{c}} \leq 0$, the equilibrium γ_H might fall to $\underline{\gamma}$, at which the demand for enforcement is zero. In case γ_H is bounded away from $\underline{\gamma}$ for any G, the demand should be strictly positive as G grows. Note that by remark 1, $\underline{\underline{c}} < 0$ is equivalent to $\delta < \delta_L$, δ_L being the lower root of $P(\delta)$, as defined in (15). It is easy to verify that (1) $\delta_L(\omega) > 1/2$ iff $\omega > 1/2$, (2) $\delta_L(\omega) > \omega$ for any $\omega \in \left(\frac{1}{2}, 1\right)$. If ω is below $\frac{1}{2}$, then $\underline{\underline{c}} > 0$, then by for big enough G, the demand D^* is zero. Now assume $\delta \in [\omega, \delta_L]$. As G approaches infinity, F approaches

$$f_0(\gamma) = \left(\omega + \delta\omega - \delta\omega^2 - 1 + \gamma(\omega - \delta - \delta\omega + 1) + \gamma^2\left(\delta\omega^2 - \delta\right)\right), \qquad (18)$$

which also implies that the upper root of F approaches the upper root of $f_0(\gamma)$.[18] Recall also that γ_H is decreasing in G. In order to find out whether γ_H will ever approach $\underline{\gamma}$, we only need to check the sign of $f_G\left(\underline{\gamma}\right)$. If it is positive, γ_H will be always above $\underline{\gamma}$. In the other case, for G big enough γ_H will reach $\underline{\gamma}$, at which the demand is zero. Observe that the sign of $f_G\left(\underline{\gamma}\right)$ depends on δ and ω :

$$f_G\left(\underline{\gamma}; \delta, \omega\right) = 2(1-\delta\omega)\frac{W(\delta,\omega)}{(\delta + \delta\omega - 2)^2} \qquad (19)$$

$$W(\delta,\omega) \equiv 3\omega - 1 + \delta^2\left(\omega + \omega^2\right) + \delta\left(-2\omega - 2\omega^2\right). \qquad (20)$$

[18] For that we just have to assure that the real roots are well defined, which is true because $\underline{\underline{c}}(\phi) < 0$ for any G, thus making the discriminant, $H_F > 0$ for any $c > 0$. Besides, as we consider $c < \underline{c}$, a_F is bounded away from zero, so the roots are continuous functions of the coefficients, a_F, b_F, k_F.

W has two δ-roots, both positive, the lower one being between zero and unity, as $W(1,\omega) = -(1-\omega)^2 < 0$ and $W(0,\omega) = 3\omega - 1 > 0$. Let us denote this root by $\bar{\delta}$,

$$\bar{\delta} \equiv 1 - \frac{(1-\omega)}{(\omega(\omega+1))^{1/2}} \tag{21}$$

thus we know $W(\delta,\omega) > 0$ for $\delta < \bar{\delta}$, which also means $f_G(\underline{\gamma};\delta,\omega) > 0$ in this range. As we are considering the case $\delta_L > \delta > \omega > 1/2$, one has to check how $\bar{\delta}$ compares with these bounds. It is easy to verify that $\delta_L > \bar{\delta}$. Next, $\bar{\delta} > \frac{1}{2}$ is true iff $\omega > \frac{3}{2} - \frac{1}{6}\sqrt{33}$. Finally, $\bar{\delta} > \omega$ iff

$$\omega > \underline{\omega} \equiv \frac{1}{2}\sqrt{5} - \frac{1}{2}\left(> \frac{3}{2} - \frac{1}{6}\sqrt{33}\right). \tag{22}$$

Note that for any fixed ω, $W(\delta,\omega) > 0$ for $\delta \in [0,\bar{\delta}]$ and $W(\delta,\omega) < 0$ for $\delta \in [\bar{\delta},1]$. Besides, $f_G(\underline{\gamma};\delta,\omega)$ has the same sign as $W(\delta,\omega)$.

To summarize, if $\omega > \underline{\omega}$ and $\delta \in (\omega,\bar{\delta})$, then $f_G(\underline{\gamma};\delta,\omega) > 0$, which implies $\gamma_H > \underline{\gamma}$ in this parameter range for any G. Otherwise, (if $\bar{\delta} \le \omega$) by considering $\delta > \omega$, we necessarily have $\delta > \bar{\delta}$, implying $f_G(\underline{\gamma};\delta,\omega) < 0$, thus for G big enough γ_H reaches $\underline{\gamma}$ and so $D^* = 0$. ■

Proof of proposition 3. First, we consider the case that where $c \in (\underline{c}, \underline{c})$, and $c > c^D$. The assumption ensures that $\gamma_H < 1$ is well-defined and that the demand for enforcement D^* is positive. Let

$$z_\gamma = \frac{(\delta\omega - 1)(\delta - 2)}{(\gamma\delta\omega - \delta\omega + 1)^2} > 0 \tag{23}$$

$$z_\omega = \frac{(\delta - 2)(\gamma - 1)\gamma\delta}{(\gamma\delta\omega - \delta\omega + 1)^2} > 0 \tag{24}$$

$$z_\delta = \frac{(2\gamma\omega - 2\omega + 1)\gamma}{-(\gamma\delta\omega - \delta\omega + 1)^2} < 0 \text{ if } \gamma > \underline{\gamma} > \frac{2\omega - 1}{2\omega} \tag{25}$$

Then

$$\frac{dD^*(\cdot)}{d\delta} = \frac{G}{2}\left[z_\delta + z_\gamma \frac{\partial\gamma_H(\cdot)}{\partial\delta}\right] \tag{26}$$

In the view of (25) and (23), it is sufficient to show $\frac{\partial\gamma_H(\cdot)}{\partial\delta} < 0$.For that it is enough to verify that the polynomial, $F(\cdot)$ is decreasing with δ, as it implies that its upper root, γ_H, is decreasing with δ as well (similar to the argument in lemma 1). In the relevant range of c, $\frac{\partial}{\partial\delta}F(\cdot) < 0$, provided $\gamma + \gamma\omega - \omega > 0$, which holds because we only consider equilibria above $\underline{\gamma}$, and $\frac{\omega}{1+\omega} < \underline{\gamma}$.

Next, we have to show that

$$\frac{dD^*}{d\omega} = \frac{G}{2}\left[z_\omega(\cdot) + z_\gamma \frac{\partial \gamma_H(\cdot)}{\partial \omega}\right] > 0 \tag{27}$$

In view of (24) and (23), it is sufficient to verify $\frac{\partial \gamma_H(\cdot)}{\partial \omega} > 0$, which is, again, implied by $\frac{\partial}{\partial \omega} F(\cdot) > 0$. The last inequality follows (in the view of definition of F, equation 9) from two observations. First,

$$\frac{\partial}{\partial \omega} V_r^g = \frac{((G+C)(\delta - 1) - C(1-\gamma\delta) - G)(\gamma + 1)}{(\gamma\delta\omega - \gamma\delta - \delta\omega - \delta + 2)^2} < 0 \tag{28}$$

Second, $\frac{\partial}{\partial \omega} V_t^g > 0$. Therefore, γ_H increases with ω, if $c \in (\underline{\underline{c}}, \underline{c})$, and $c > c^D$.

If $c \geq \underline{c}$, $\gamma_H = 1$, so this case is trivial. ■

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