# Trust and Vulnerability*

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**Abstract**

By facilitating mutually beneficial transactions, trust is a crucial ingredient for economic development. We study a model in which agents rely on imperfectly enforceable contracts to support cooperation in a prisoners' dilemma production game. The model is used to explore the determinants of trust, as measured by the ex-ante probability with which an agent chooses the co-operative action, with a particular focus on vulnerability, as inversely measured by the payoff when cheated. We show how a fundamental relationship between vulnerability and trust emerges when players observe private signals of the strength of contract enforceability, even in the limit as signal noise vanishes. In uncovering this relationship, the model demonstrates the importance of social institutions in the development process. We show stronger social institutions, by reducing vulnerability, increase equilibrium trust, promote the use of superior technologies, and interact with formal legal institutions.

**Keywords**: trust, global games, institutions, social protection

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# 1 Introduction

Virtually every economic transaction entails scope for opportunism, and therefore *trust* – a willingness to place oneself in a vulnerable position – is a critical ingredient for economic development.[1] In understanding the sources of trust, economists typically take the view (as we do in this paper) that individuals are willing to place themselves in vulnerable positions when there are weak incentives for others to exploit such vulnerabilities. This type of analysis quickly leads to the conclusion that trust flourishes when there are a strong set of legal institutions within which courts are willing and able to enforce contracts and mete out appropriate punishments.[2]

While this approach has considerable intuitive appeal, the role of *vulnerability* is conspicuously absent. In the simplest specification, trust is extended if and only if the counter-party does not find it optimal to cheat. But whether there are incentives to cheat is independent of the consequences felt by the trusting party. Vulnerability may play a role in richer specifications, e.g. with unobserved heterogeneity in incentives to cheat, since there may always be a positive probability of being cheated. Regardless, the broad conclusion is that the strength of the relationship between vulnerability and trust is limited by the extent to which trust violations occur in equilibrium.

In this paper we argue that there is a more fundamental relationship between vulnerability and trust, and as a result, that there is a more significant role for social policy in promoting economic development. We show that this relationship is strong and persists in the absence of equilibrium trust violations. We show how this relationship only manifests itself when we take seriously the mutual uncertainty that is at the heart of trust. This uncertainty is more than individual $A$'s uncertainty of the payoffs from cheating, and is also more than individual $B$'s uncertainty of $A$'s payoffs or even $B$'s uncertainty of the extent of $A$'s uncertainty. If $A$'s optimal action depends on the action taken by $B$, then $A$'s uncertainty of $B$'s uncertainty will also matter in determining $A$'s optimal action. Of course, $B$ will face uncertainty over that level of $A$'s uncertainty, and so on *ad infinitum*.

Specifically, we model a situation in which two agents play a prisoners' dilemma in the shadow of imperfectly enforced contracts.[3] That is, agents rely on legal institutions to support productive

[1]Empirical evidence connecting trust and development is presented in Knack and Keefer (1997) and Zak and Knack (2001) among many others.

[2]We focus on this aspect as our model is static, however, formal institutions are not always required in dynamic settings where incentives to cheat are curtailed because of repeated interaction, perhaps with group punishment (e.g. Greif (1994), Dixit (2003)). Nevertheless, the point being made here applies equally well to these settings. Legal institutions also play a role in models in which the trustworthiness of a population is subject to evolutionary forces, such as Francois and Zabojnik (2005), Tabellini (2008), Bidner and Francois (2011), and Jackson (2011).

[3]We use a standard simultaneous-move prisoners' dilemma. Much analysis of trust, both theoretical and experi-

interactions in which both sides have private incentives to cheat. In order to deal with the tangled web of mutual uncertainty described above, we follow the elegant approach adopted in the global games literature (Carlsson and van Damme (1993), Morris and Shin (2003)). Specifically, neither agent knows the strength of contracting institutions with certainty, but each observes a private noisy signal of this, and chooses whether to cheat on the basis of this signal. In the limit as the noise on the signal vanishes to zero, the extent of trust violation (here, one side cooperating while the other defects) goes to zero. In order to stress the 'deep' nature of the relationship between vulnerability and trust, we are primarily interested in this limit case.

We begin with a baseline model in which the strength of contracting institutions is common knowledge and show that vulnerability (as inversely measured by the payoff when cheated) has no impact on trust (as measured by the ex-ante probability that a player will cooperate).We then show how an impact emerges in the presence of behavioral types that always defect, but that the magnitude of this impact quickly declines to zero as the measure of behavioral types goes to zero. We then abandon common knowledge of contracting institutions by allowing agents to observe private noisy signals as described above. In this setting we show that vulnerability has an effect on trust, even in the limit as signal noise goes to zero.[4] This result reflects the phenomenon, highlighted in related contexts (e.g. Schelling (1960), Carlsson and van Damme (1993), van Damme (1995)), whereby only a "grain of doubt" about the actions of opponents is sufficient to dramatically alter equilibrium outcomes. We then use this result to demonstrate the ways in which the baseline model produces results qualitatively different from the model with signal noise taken to zero.

We show how stronger social institutions, by reducing vulnerability, play a role in enhancing trust. The mechanism is more subtle than simply a lower vulnerability leading to a greater

mental, instead use a 'one-sided' prisoners' dilemma in which a Truster chooses whether to extend trust, and if so, the Trusted decides whether to honor such trust. This situation reverts back to a two-sided version in many applications of interest when the Truster also takes some costly unobserved action that benefits the Trusted. For instance, the Truster promises to install capital that will enhance the human capital investment made by the Trusted, or the Truster refrains from consuming the bonus that is promised to the Trusted. Rather than imposing this extraneous structure, we adopt a simpler symmetric specification. Having sequential moves also greatly complicates the belief updating process without adding substance.

[4] In the context of a repeated prisoners' dilemma, Blonski *et al.* (2011) also make the point that vulnerability (or, in their language, the "sucker's payoff") should reasonably be expected to matter for sustaining cooperation, despite the fact that it does not in standard treatments. Their experimental results are highly supportive of the notion that vulnerability matters for sustaining cooperation. Whereas we allow vulnerability to play a role via mutual uncertainty of the strength of contracting institutions, Blonski *et al.* (2011) directly incorporate the feature into their set of equilibrium selection axioms.

willingness to bear the risk associated with cooperation. Rather, this greater willingness to cooperate raises the counterparty's willingness to cooperate since they are less likely to be cheated. Their greater willingness to cooperate then further raises one's willingness to cooperate, which then further raises the counterparty's willingness to cooperate, and so on. After providing this result, we perform a complementary analysis that shows how reduced vulnerability allows for the employment of superior technologies, and how social institutions interact with legal institutions in raising trust.

The impact of vulnerability on trust greatly heightens the role of social policy in the development process. Social policies (such as conditional and unconditional transfers and the provision of a social safety net) expand the range of circumstances in which trust is extended, and thereby raise income via the promotion of trade. This role is over and above other roles identified in the literature, such as overcoming market failures in the provision of credit and insurance (see Dercon (2011) and the 2010 European Report on Development ERD (2010)).

The empirical literature suggests a positive relationship between the strength of social institutions and trust. Rothstein (2001) and Kumlin and Rothstein (2005) argue that the high levels of trust in Scandinavian countries are a direct result of generalized social programs that reduce vulnerability. Rothstein and Uslaner (2005) and Freitag and Bühlmann (2009) generalize these and use cross-country data to show that the presence of an effective welfare state is associated with higher trust. To the extent that inequality is symptomatic of weak social institutions,[5] further support is provided by the extensive evidence linking high inequality to low levels of trust; e.g. Alesina and Ferrara (2002), Costa and Kahn (2003, 2004) and Bjørnskov (2007). Although causality is rarely convincingly established in this literature (Bjørnskov (2007) and Bergh and Bjørnskov (2011)), we take this evidence as suggestive of the need for a convincing theory of the causal relationship between strong social institutions and trust.

The global games framework, introduced by Carlsson and van Damme (1993) and surveyed in Morris and Shin (2003), was initially concerned with issues of equilibrium selection. Among more recent applications are those concerned with various aspects of economic development: borrower runs in micro-finance (Bond and Rai (2009)), the analysis of conflict (Chassang and Padro i Miquel (2009) and Chassang and Padro i Miquel (2010)), and racial tensions Basu (2005) to name a few. In each case, the presence of small amounts of uncertainty over an underlying parameter fundamentally alters the outcome relative to the situation without uncertainty. In a more general setting, Chassang (2010) studies a repeated relationship in which players decide

[5] Gustavsson and Jordahl (2008) provide evidence from Sweden that it is inequality of *disposable* income at the *bottom* of the distribution that matters for trust, and the relationship is stronger among those who report that they are more averse to inequality.

whether to leave the relationship each period when both players face uncertainty over the value of remaining in the relationship each period. One implication of his analysis is that the capacity for productive relationships to remain intact depends on the payoff arising when the other player abandons the relationship, even when the true value of remaining in the partnership is observed with arbitrarily small noise. Although similar in this respect, that work stresses 'miscoordination' rather than trust violation and as a result does not explore the role of various institutions as we do here.

In the next section, we introduce the model: the baseline model with common knowledge is laid out in section 2.1, whereas the global games version is laid out in 2.2. After presenting a number of results comparing the two approaches, we turn to section 3 in which we discuss the role of policy, paying attention to role of social institutions in increasing the level of trust, facilitating the employment of superior technologies, and interacting with formal legal institutions. Conclusions are briefly drawn in section 4. All proofs are contained in appendix A.

# 2 A Model

## 2.1 A Base Model

### 2.1.1 Fundamentals

We begin with a simple benchmark model in which a pair of agents are presented with a project that requires cooperation. If the project is undertaken, each agent simultaneously chooses whether to cooperate or defect. If neither party cooperates, each produces an output normalized to one. Cooperation is productive, but there are incentives to defect: if both agents cooperate each produces an output of $r > 1$, and if one agent cooperates while their partner defects, then the cooperator produces an output of $s \in [0, 1)$ and the defecting agent produces an output of $t > r$. In other words, the agents are presented with a prisoners' dilemma. To ensure that cooperation is efficient, we assume $2r \geq t + s$.

This production environment is overlaid with a set of imperfect legal institutions. Specifically, the agreement between agents is verifiable by the courts with probability $\theta \in [0, 1]$. If an agent was found to have chosen 'defect' while their partner had chosen 'cooperate', then the defector is fined an amount $F$, where we assume $F > t - r$ (to avoid the trivial case where the fine is so small that cheating with certain punishment is preferred to cooperation). No fines are levied by the courts if both players defect. With probability $1 - \theta$ the agreement is non-verifiable and no fines are imposed.

The value of $\theta$ depends on the specifics of the project and therefore varies across projects.

To model this we suppose that $\theta$ depends on an underlying state, $\omega \in \mathbb{R}$, where $\omega$ is normally distributed: $\omega \sim N(\omega_0, \sigma_0^2)$. The extent to which the contract is enforceable is given by $\theta \equiv g(\omega)$, where $g : \mathbb{R} \to (0,1)$ is a strictly increasing differentiable bijective function.[6] The parameter $\omega_0$ is therefore a proxy for the overall quality of legal institutions.

If agents prefer not to engage the project at all, they can always produce an output of $y$ autonomously. To make matters non-trivial, we assume that $y \in [1, r]$ (so that cooperative production is preferred to autonomous production, which is preferred to mutual defection).

The timing of the model is as follows.

1. Both agents simultaneously decide whether they want to engage the project. If at least one party does not wish to engage the project then both parties produce autonomously and the game ends. Otherwise,
2. The agents decide whether they wish to enter into an agreement that specifies mutual cooperation.
3. The value of $\omega$ is realized.
4. Agents decide whether to cooperate or defect, and payoffs are realized.

### 2.1.2 Equilibria

As usual, we begin the analysis in the final stage - the 'production' subgame. Since $\theta = g(\omega)$, observing $\omega$ is equivalent to observing $\theta$. Given this value, the payoffs are those given in the following matrix.

| | $C$ | $D$ |
|---|---|---|
| $C$ | $u(r), u(r)$ | $u(s), \theta \cdot u(t-F) + (1-\theta) \cdot u(t)$ |
| $D$ | $\theta \cdot u(t-F) + (1-\theta) \cdot u(t), u(s)$ | $u(1), u(1)$ |

If player $i$ expects their partner to play $C$ with probability $p_i$, then the payoff to playing $C$ is:

$$u^C = p_i \cdot u(r) + (1-p_i) \cdot u(s),$$

and from playing $D$ is

$$u^D = p_i \cdot [(1-\theta) \cdot u(t) + \theta \cdot u(t-F)] + (1-p_i) \cdot u(1).$$

Thus, player $i$ finds it optimal to play $C$ if and only if $\theta$ is sufficiently high:

$$\theta \geq \frac{u(t) - u(r) + \left[\frac{1-p_i}{p_i}\right] \cdot (u(1) - u(s))}{u(t) - u(t-F)}. \tag{1}$$

[6] Being a bijection ensures that every $\theta \in (0,1)$ is generated by some $\omega \in \mathbb{R}$.

The right side of this inequality is a strictly decreasing function of $p_i$, becoming infinitely large as $p_i \to 0$ and taking on the value of

$$\theta^{**} \equiv \frac{u(t) - u(r)}{u(t) - u(t - F)} \tag{2}$$

at $p_i = 1$.

**Proposition 1.** *The strategy profile $(D, D)$ is always a Nash equilibrium of the production subgame. The strategy profile $(C, C)$ is a Nash equilibrium of the production subgame if and only if contract enforceability is sufficiently strong: $\theta \geq \theta^{**}$.*

By noting that $(C, D)$ and $(D, C)$ are never equilibria,[7] we have (i) for any realized $\theta < \theta^{**}$ the unique equilibrium in the production subgame involves mutual defection, and (ii) for any realized $\theta \geq \theta^{**}$ there are two (pure strategy) equilibria of the production subgame: one that involves mutual defection and one that involves mutual cooperation. We argue that the feasibility of entering into an ex-ante agreement makes mutual cooperation focal and therefore assume from here that the cooperative equilibrium is played in the production subgame whenever it exists.

While perhaps straightforward, this analysis provides an important benchmark for the results that follow. To this end, it is useful to quantify *trust* at this point. We measure *trust* as the ex-ante probability that a player will choose $C$ in the production subgame.[8] Given that players cooperate for sufficiently high realizations of $\theta$, we have that trust is the ex-ante probability that the underlying state is sufficiently high - specifically, the probability that $\omega > g^{-1}(\theta^{**})$. The equilibrium level of trust is therefore given by

$$\tau^{**} \equiv 1 - \Phi\left(\frac{g^{-1}(\theta^{**}) - \omega_0}{\sigma_0}\right), \tag{3}$$

where $\Phi$ is the cdf of the standard normal distribution.

The expected payoff in the production subgame is $\tau^{**} \cdot u(r) + (1 - \tau^{**}) \cdot u(1)$, and therefore there is no subgame perfect equilibrium in which players engage the project if trust is sufficiently low. To avoid this uninteresting case, we assume that $\tau^{**} \geq (u(y) - u(1))/(u(r) - u(1))$ (e.g. $y \leq 1$ is sufficient) so that we can focus on equilibria in which the project is engaged.[9] In summary, we focus on the subgame perfect equilibrium in which both players engage the project, then

[7] Since $D$ is the unique best response to $D$.

[8] The propensity to take action $C$ can be seen as indicating both how trusting a player is (since this action leaves them exposed to cheaters) and how trustworthy they are (since this is the 'promised' action).

[9] Of course, there are always subgame perfect equilibria in which the project is not engaged even when $\tau^{**} \geq (u(y) - u(1))/(u(r) - u(1))$ and both players anticipate the cooperation equilibrium to be played in the production subgame whenever it exists. This arises purely because both players need to engage the project, and therefore 'not engage' is a best response to 'not engage'. These equilibria are not compelling (e.g. they need not exist if the decision to engage the project were made sequentially) and we ignore them.

cooperate if $\theta \geq \theta^{**}$, and defect otherwise. The level of trust, as given by (3), then also tells us the ex-ante probability that the players cooperate.

Notice that the equilibrium level of trust depends only on the consequences of cheating, but *not* on the consequences of being cheated. That is, trust is decreasing in the potential gains from cheating $(t - r)$, is increasing in the level of the fine $(F)$ and overall institutional quality $(\omega_0)$, but is independent of the extent of vulnerability $(y - s)$.

In this base model, this counter-intuitive disconnect between trust and vulnerability arises because players are cheated with probability zero on the equilibrium path. To see this, suppose that a proportion $\varepsilon$ of players are *bad* types who always defect[10], whereas the remaining players are *regular* types with preferences as described in the base case above. The above analysis goes through except $p_i = 1 - \varepsilon$ in condition (1). As a result the equilibrium cutoff is modified to

$$\theta^{**}(\varepsilon) \equiv \frac{u(t) - u(r) + \left[\frac{\varepsilon}{1-\varepsilon}\right] \cdot (u(1) - u(s))}{u(t) - u(t - F)}, \tag{4}$$

and, as long as $\theta^{**}(\varepsilon) < 1$, equilibrium trust is

$$\tau^{**}(\varepsilon) \equiv 1 - \Phi\left(\frac{g^{-1}(\theta^{**}(\varepsilon)) - \omega_0}{\sigma_0}\right). \tag{5}$$

A regular type is cheated with an ex-ante probability of $\tau^{**}(\varepsilon) \cdot \varepsilon$, which is strictly positive if and only if $\varepsilon > 0$. Furthermore, the strength of the relationship between trust and vulnerability as captured by $d\tau^{**}(\varepsilon)/ds$, is easily seen to be positive but proportional to $\varepsilon/(1-\varepsilon)$. Specifically, we have $\lim_{\varepsilon \to 0} d\tau^{**}(\varepsilon)/ds = 0$. In other words, there is a non-negligible relationship between trust and vulnerability only if there is a non-negligible probability of being cheated in equilibrium.

We argue that there is a more fundamental relationship between trust and vulnerability – indeed, a relationship that persists even when there is an arbitrarily small probability of being cheated in equilibrium. This relationship is overlooked in the base model because of the assumption that the realization of $\theta$ is common knowledge. This assumption rules out the sort of mutual uncertainty discussed in the introduction. To see why this matters, note that common knowledge of $\theta$ allows players great freedom in forming conjectures about the action taken by their partner.[11] Specifically, $\theta^{**}$ is the value of $\theta$ that makes a player indifferent between their actions under the conjecture that their partner plays $C$ with probability one. Such a conjecture is surely unrealistically extreme if the players have (even slightly) different beliefs about $\theta$. This is

[10] This is perhaps because they experience some very high payoff from defecting, or because they are 'above the law' and only ever experience low fines (zero, say).

[11] To be sure, this argument does not rely on players knowing the actual value of $\theta$. What is important is that players have *exactly the same* information. In other words, the argument would apply equally well if we instead assumed the players both observed a public signal of the true value of $\theta$.

because the other player will play $C$ with probability zero if they happened to believe $\theta$ is below the cut-off (a relatively high probability event in the eyes of a player exactly at the cut-off). The following section uses the theory of global games to illuminate such issues further.

## 2.2 A Global Games Approach

In contrast to the preceding section, we now suppose that players are imperfectly informed about the institutional quality governing their interaction. The structure of the model is the same except that at stage 3, each player now receives a signal, $\tilde{\omega}_i$, of the true underlying state, $\omega$. Following the global games literature (Morris and Shin (2003)), we assume that this signal is normally distributed, centered on the true state: $\tilde{\omega}_i \sim N(\omega, \sigma^2)$. The extent of signal noise is captured by $\sigma^2$, and in order to stress the fundamental nature of the relationship between trust and vulnerability, we will primarily be interested in the limit case where this noise goes to zero.

Using the well-known properties of the normal distribution (De Groot (1970), p. 167), we have that the posterior distribution is $\omega \mid \tilde{\omega}_i \sim N(\bar{\omega}_i, \sigma_1^2)$, where

$$\bar{\omega}_i \equiv \frac{\sigma_0^2}{\sigma_0^2 + \sigma^2} \cdot \tilde{\omega}_i + \frac{\sigma^2}{\sigma_0^2 + \sigma^2} \cdot \omega_0, \text{ and } \sigma_1^2 \equiv \frac{\sigma_0^2 \sigma^2}{\sigma_0^2 + \sigma^2}. \tag{6}$$

It is straightforward to show that signals are informative about the state: player $i$'s expectation of $\theta$ conditional on their signal, $\mathbb{E}[\theta \mid \tilde{\omega}_i]$, is strictly increasing in $\tilde{\omega}_i$ (see appendix B). In addition to being informative about the state, player $i$'s signal is also informative about the signal received by the their partner. This is a natural consequence of the fact that both players receive signals about the same underlying state and therefore find that their signals are positively correlated. To show the relationship between $i$'s signal and their beliefs about the distribution of their partner's signal, we begin by noting that $\tilde{\omega}_{-i} \sim N(\omega, \sigma^2)$ and that $i$ believes $\omega \mid \tilde{\omega}_i \sim N(\bar{\omega}_i, \sigma_1^2)$. From $i$'s perspective then, $\tilde{\omega}_{-i} \mid \tilde{\omega}_i \sim N(\bar{\omega}_i, \sigma_1^2 + \sigma^2)$ (see Morris and Shin (2003); p. 79).

A player's strategy in the production subgame now is a map from signals to actions. It is still an equilibrium to play $D$ for all signals (since $D$ is the unique best response to $D$ for any value of $\theta$). It is not an equilibrium to play $C$ for all signals, but there may exist equilibria in which players play $C$ for *some* signals. Given that higher signals raise the expected punishment resulting from playing $D$, along with strategic complementarities, we naturally focus on cut-off equilibria. That is, equilibria in which players play $C$ if and only if signals are sufficiently high.

If $-i$ uses a cut-off strategy of playing $C$ if $\tilde{\omega}_{-i} > x$ and $D$ otherwise, then, for any $\tilde{\omega}_i$, player $i$ perceives that the probability that $-i$ will play $C$ is

$$p(\tilde{\omega}_i, x) = 1 - \Pr[\tilde{\omega}_{-i} \leq x \mid \tilde{\omega}_i] = 1 - \Phi\left(\frac{x - \bar{\omega}_i}{\sqrt{\sigma_1^2 + \sigma^2}}\right), \tag{7}$$

where $\bar{\omega}_i$ and $\sigma_1^2$ are given by (6). Intuitively, the probability that the other player will cooperate is higher when one receives a higher signal (since this is indicative of the other player also receiving a higher signal) and lower when the other player is using a higher cut-off: i.e. $p$ is increasing in $\tilde{\omega}_i$ and decreasing in $x$.

Given $x$, it is optimal for $i$ to play $C$ if

$$\mathbb{E}[\theta \mid \tilde{\omega}_i] \geq \frac{u(t) - u(r) + \left[\frac{1-p(\tilde{\omega}_i,x)}{p(\tilde{\omega}_i,x)}\right] \cdot (u(1) - u(s))}{u(t) - u(t-F)}. \tag{8}$$

The left side is increasing in $\tilde{\omega}_i$ whereas the right side is decreasing in $\tilde{\omega}_i$. It then follows that $i$'s best response is also a cut-off strategy. Let the cut-off value be denoted $b(x)$, and note that $b = +\infty$ corresponds to 'always play $D$' and $b = -\infty$ corresponds to 'always play $C$'. It is straightforward to see that there is never an equilibrium in which both players always play $C$ (since $D$ is a best response for sufficiently low signals), so if there is a cut-off equilibrium with $C$ being played with positive probability we must have $b \in (-\infty, +\infty)$. In this case, $b$ is the signal that makes $i$ indifferent between their actions, and is therefore implicitly defined by

$$\mathbb{E}[\theta \mid b(x)] = \frac{u(t) - u(r) + \left[\frac{1-p(b(x),x)}{p(b(x),x)}\right] \cdot (u(1) - u(s))}{u(t) - u(t-F)}. \tag{9}$$

The right side is increasing in $x$ and decreasing in $b$, whereas the left side is independent of $x$ and increasing in $b$ (see appendix B). As a result, the best response function is strictly increasing. Given symmetry, an equilibrium cut-off has the property $x^* = b(x^*)$, and therefore satisfies

$$\mathbb{E}[\theta \mid x^*] = \frac{u(t) - u(r) + \left[\frac{1-p(x^*,x^*)}{p(x^*x^*)}\right] \cdot (u(1) - u(s))}{u(t) - u(t-F)}. \tag{10}$$

The expression $p(x^*, x^*)$ is player $i$'s assessment of the probability that $-i$ will cooperate conditional on $i$ receiving a signal equal to $-i$'s cut-off of $x^*$. For values of $x^*$ above the prior, $\omega_0$, $i$ finds it more likely than not that $-i$ has a lower signal (think of the extreme case in which there is infinite noise on the signal). The reverse is true for values of $x^*$ below $\omega_0$. This intuition that $p(x^*, x^*)$ is decreasing in $x^*$ is confirmed by noting that

$$p(x^*, x^*) = 1 - \Phi\left(\sqrt{\frac{\sigma^2}{\sigma^2 + \sigma_0^2}} \cdot [x^* - \omega_0]\right). \tag{11}$$

We explore equilibria in the limit as signal noise goes to zero. First, since the signal reveals the true state, we have that $\lim_{\sigma\to 0} \mathbb{E}[\theta \mid x^*] = g(x^*)$ (see appendix B). Furthermore, from (11) we see that, for any $x^* \in (-\infty, \infty)$, we have that $\lim_{\sigma\to 0} p(x^*, x^*) = 1/2$. That is, each player finds that there is a 50% chance that the other player has a higher signal. Using these two results in (10) indicates that in the limit as signal noise goes to zero, we have that the equilibrium cutoff satisfies:

$$g(x^*) = \frac{u(t) - u(r) + u(1) - u(s)}{u(t) - u(t-F)} \equiv \theta^*. \tag{12}$$

As a result, we have the following.

**Proposition 2.** *If $\theta^* < 1$, a unique cut-off equilibrium in which $C$ is played with positive probability exists. In this equilibrium players use a cut-off of $x^* = g^{-1}(\theta^*)$.*

In the limit case, as long as $\theta^* < 1$, the equilibrium level of trust is the probability that the state is sufficiently high:

$$\tau^* \equiv 1 - \Phi\left(\frac{g^{-1}(\theta^*) - \omega_0}{\sigma_0}\right). \tag{13}$$

The probability that a player is cheated in this equilibrium is the probability that players receive signals either side of the cut-off. The probability of this event goes to zero as signal noise goes to zero (see appendix B for details). The expected payoff from engaging the project is therefore $\tau^* \cdot u(r) + (1 - \tau^*) \cdot u(1)$, and therefore there is a subgame perfect equilibrium in which the project is engaged if $\tau^* \geq (u(y) - u(1))/(u(r) - u(1))$ (again, $y \leq 1$ is sufficient).

### 2.2.1 A Comparison to the Base Case

It is seemingly irrelevant whether one models an economy with zero signal noise (common knowledge of contract enforceability) or takes the longer route of allowing for signal noise then taking this to zero. For instance, the probability of being cheated in equilibrium is zero in both cases. In this section we briefly outline the ways in which the two approaches produce different results, thereby making the point that care needs to be taken in making modeling choices when studying phenomena involving mutual uncertainty such as trust.

The most clear result in this respect, that the equilibrium trust levels are different, follows from the simple observation that $\theta^* \neq \theta^{**}$.

**Proposition 3.** *Equilibrium trust in the limiting case as noise goes to zero does not equal equilibrium trust under the assumption of no noise: $\tau^* \neq \tau^{**}$. In particular, trust is lower in the former case: $\tau^* < \tau^{**}$.*

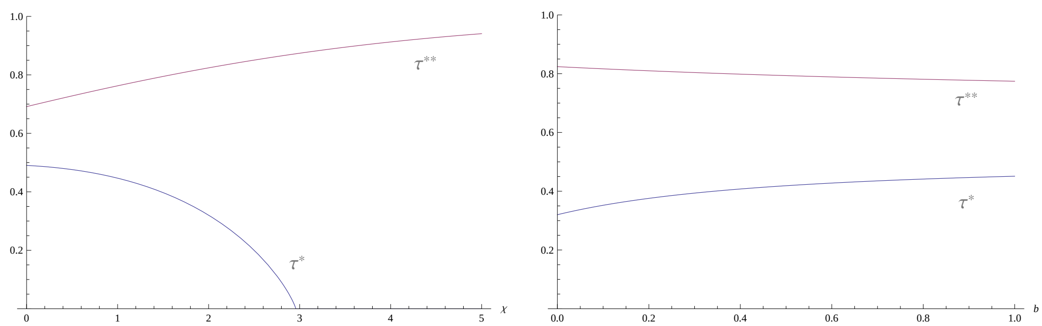
Is the magnitude of the difference in equilibrium trust levels significant? One way to gauge this is to ask how pervasive bad types need to be in the base model in order to produce a trust level equal to that arising in the 'global games' version. The following result indicates that the difference in trust predicted by the two approaches is quite sizeable.

**Proposition 4.** *Trust in the global games version equals trust in the base model with half the population being bad types: $\tau^* = \tau^{**}(\varepsilon)_{|\varepsilon=0.5}$.*

The two approaches can produce different relationships between preference parameters and trust. To illustrate, let $u$ be given by the constant relative risk aversion form:

$$u(c) = \frac{(c+b)^{1-\chi}}{1-\chi}, \tag{14}$$

where $b \geq 0$ is a baseline consumption and $\chi \geq 0$ is the Arrow-Pratt measure of relative risk aversion. To explore the relationship between trust and risk aversion, Figure 1(a) displays numerical results.[12]




(a) Risk Aversion

(b) Baseline Consumption

Figure 1: Trust and Utility Parameters

We see that the base case implies a somewhat counter-intuitive positive relationship between risk aversion and trust.[13] The reason is that greater risk aversion makes the possible punishment more salient, thereby reducing the temptation to cheat. In the limit case the relationship is negative (when $s < t - F$), reflecting the intuition that losses from being cheated become more salient as aversion to risk intensifies. Indeed, the figure shows that trust-based trade collapses for sufficiently risk averse players. This result is consistent with the experimental literature, where Schechter (2007) shows that higher levels of risk aversion are associated with lower levels of trust.

A similar implication arises when exploring the relationship between baseline consumption and trust, as shown in Figure 1(b).[14] Greater baseline consumption acts to reduce (absolute) risk aversion. For these parameters, trust increases in $b$ for the base case and decreases in $b$ for the limit case.

Finally, vulnerability, as reflected in the value of $s$, has an impact on trust even in the limit as

[12] The parameters used are $t = 2$, $r = 1.5$, $F = 1$, $s = 0.8$, $b = 0$, $\omega_0 = 0.5$ and $\sigma_0 = 1$. We take $g$ to be the cdf of the standard normal distribution.

[13] Breuer and McDermott (2011) show how a 'culture of caution', where people are more averse to losses, leads to greater levels of trust. As here, the reasoning is that cautious societies tend to be more trustworthy since the aversion to loss magnifies the impact of being caught and punished when cheating.

[14] The figure uses $\chi = 2$.

noise goes to zero. This is in contrast to the base case in which the state is common knowledge. The fact that $\theta^*$ is sensitive to $s$ whereas $\theta^{**}$ is not gives us the following.

**Proposition 5.** *Unlike in the base model, there is a relationship between vulnerability and trust in the 'global games' version even in the limit where the probability of being cheated vanishes to zero. That is,* $\frac{d\tau^*}{ds} \neq \frac{d\tau^{**}}{ds} = 0$.

The nature of this relationship, and further implications are explored in the following section.

# 3 Discussion

This section discusses the role of 'social institutions' in fostering trust. We take 'social institutions' to be that set of policies that deliver social protections; e.g. the provision of a social safety net or forms of social insurance that soften the consequences of adverse outcomes. In terms of the model, policies that raise $s$.

The discussion proceeds along three dimensions. We first show how social institutions increase trust by facilitating cooperation over a wider range of contract enforceability levels. We then explore a complementary perspective on this analysis by showing how stronger social institutions allow more productive projects to be successfully undertaken for a given quality of contract enforceability. Finally, we consider how social institutions interact with legal institutions in the strengthening of trust.

## 3.1 Vulnerability and Trust

A central implication of the analysis is that reduced vulnerability, as captured by a higher $s$, raises trust. This is because a reduced vulnerability lowers the minimum level of contract enforceability required for cooperation to occur and thereby allows cooperation to arise for weaker levels of contract enforceability.

**Proposition 6.** *Reduced vulnerability raises trust:* $\frac{d\tau^*}{ds} > 0$.

It is important to stress that lower vulnerability does not raise trust just because the consequences of being cheated are lowered. The baseline model demonstrates that if this were the only channel, then there would be no equilibrium relationship between vulnerability and trust. The key here is that as vulnerability falls, a player becomes more optimistic about their partner cooperating (since their partner is also less vulnerable). This makes the player even more willing to cooperate, which in turn makes their partner even more willing to cooperate, which once again makes the player even more willing to cooperate, and so on. It is this feedback feature that lies at the heart of the relationship between vulnerability and trust identified here.

One way to gauge the magnitude of this relationship is to compare the effect of social institutions to the effect of other policies available to policy makers. One obvious set of policies are those aimed at increasing the value of successful projects (e.g. lowered tax rates or the provision of infrastructure) – i.e. increasing $r$.

**Proposition 7.** *In terms of raising trust, increases in $s$ are at least as effective as increases in $r$: $\frac{d\tau^*}{ds} \geq \frac{d\tau^*}{dr}$. The inequality is strict when players are risk averse.*

This result is strengthened even further by noting that increases in $s$ are costless in the model since the cheated outcome never arises in equilibrium. In contrast, the cooperative outcome arises with probability $\tau^*$ and therefore increases in $r$ entail positive costs.[15]

## 3.2 Vulnerability and Complexity

Rather than determining whether cooperation can be sustained for a fixed project for a range of contract enforceability levels, we can fix a contract enforceability level and ask which projects can be sustained. This perspective is similar to the literature that explores the relationship between the quality of a country's legal institutions and the complexity of the goods produced and exported (Nunn (2007), Acemoglu *et al.* (2007) and Levchenko (2007)). In this section we examine whether improving social protections has a similar effect by extending our model to include a simple technology choice.

Suppose now that there are a range of technologies that can be used in order to complete the project. Specifically, we think of technologies as differing in terms of the cooperative payoff, $r$, and the defect payoff, $t$. Let $\mathcal{T}$ be the set of technologically feasible $(r, t)$ pairs, where each $(r, t) \in \mathcal{T}$ satisfies the maintained assumptions of the model. Specifically, we have assumed that (i) $1 < r$ (mutual cooperation is preferred to mutual defection), (ii) $r < t$ (there is an incentive to defect from cooperation), and (iii) $t + s \leq 2r$ (one party defecting is never efficient). The set of points satisfying these three constraints is depicted in $(r, t)$ space as the vertical shaded area in figure 2(a). One example of a technologically feasible set, $\mathcal{T}$, is also depicted in this figure.

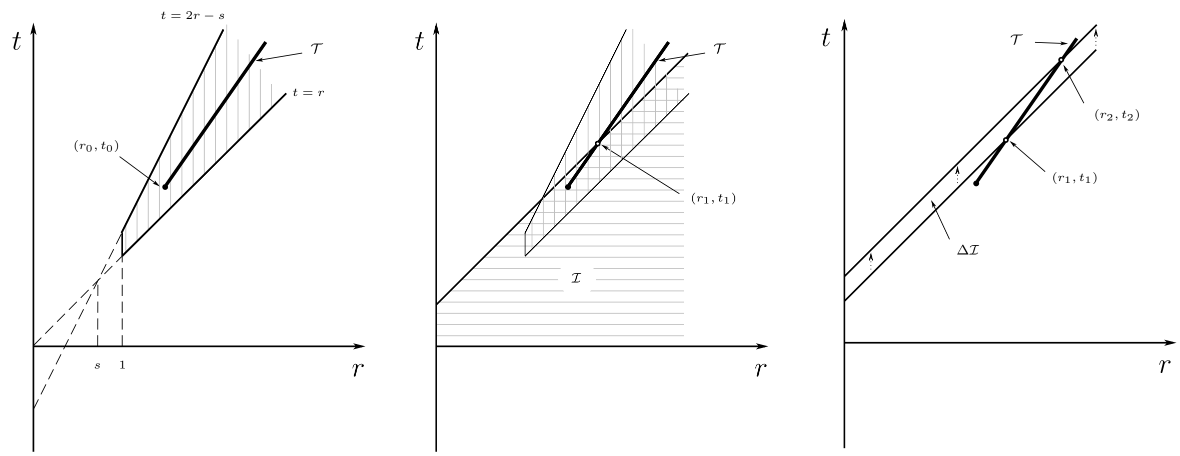
While a particular technology may be technologically feasible, it may not be incentive compatible given the quality of contracting institutions governing the interaction. Let $\mathcal{I}$ be the set of incentive compatible technologies: i.e. the set of $(r, t)$ pairs such that $\theta \geq \theta^*$. That is, the values of $(r, t)$ such that:

$$u(r) \geq (1 - \theta) \cdot u(t) + \theta \cdot u(t - F) + u(1) - u(s). \tag{15}$$

[15] Stronger social institutions are of course not costless in reality since adverse outcomes arise for many reasons apart from being cheated. However, the cost of raising $r$ in reality is also greater than that described here, for the same reason.

Since the left side is increasing in $r$ and the right side is increasing in $t$, this inequality tells us that $r$ can not be too small for a given $t$. Figure 2(b) depicts $\mathcal{I}$ for the case in which utility is linear.

The intersection of $\mathcal{T}$ and $\mathcal{I}$ is the set of technologies that are both feasible and incentive compatible. The technology with the highest cooperative payoff is chosen from this set. In the figure, this choice is technology $(r_1, t_1)$.




(a) Feasible Set (b) Incentive Compatible Set (c) Effect of lower vulnerability

Figure 2: Vulnerability and Complexity

**Proposition 8.** *Stronger social institutions expand the set of incentive compatible technologies.*

In other words, as $s$ increases, higher values of $t$ become incentive compatible for any given $r$. This change is indicated by $\Delta\mathcal{I}$ in figure 2(c), where we see that a range of superior technologies become employable. The new optimal technology is denoted $(r_2, t_2)$.

Whether or not stronger social institutions lead to the employment of superior technologies *in general* is impossible to determine without placing further structure on $\mathcal{T}$. To this end, suppose that there exists some feasible baseline technology, $(r_0, t_0)$, where $1 < r_0 < t_0$ and $t_0 + 1 \leq 2r_0$,[16] as depicted in figure 2(a). Pairs can employ technologies with higher values of $r$, but players are able to appropriate a fraction $\psi \in [0, 1]$ of their partner's additional output if they defect while their parter cooperates. That is, $t = r + \psi \cdot (r - r_0)$. Assume also that players are able to secure a fixed amount $s$ that can not be expropriated (independent of the technology used). This allows us to describe $\mathcal{T}$ by the function $t = \hat{t}(r) \equiv (1 + \psi) \cdot r - \psi \cdot r_0$ defined for $r \geq r_0$.[17]

[16]These assumptions ensure that the baseline technology satisfies the assumptions of our model for all values of $s \leq 1$.

[17]This is a convenient parameterization since the fact that $\psi \in [0, 1]$ means that if $(r_0, t_0)$ satisfies the maintained

If we assume utility is linear for simplicity, then $\mathcal{I}$ is the set of $(r, t)$ such that

$$t \leq \tilde{t}(r; s, \theta, F) \equiv r - 1 + s + \theta F.$$

To calculate the value of $r$ for the optimal technology, denoted $r^\dagger$, we simply find the value of $r$ such that $\tilde{t}(r; s, \theta, F) = \hat{t}(r)$. Simple calculation reveals that

$$r^\dagger(s, \theta, F) = r_0 + \frac{\theta F - 1 + s}{\psi}, \tag{16}$$

which is clearly increasing in $s$.

**Proposition 9.** *Stronger social institutions allow for the employment of superior technologies.*

### 3.3 Interaction with Legal Institutions

Trust is enhanced with stronger legal institutions, but how is this relationship affected by the state of social institutions? We explore this by considering the effect of an increase in the mean realized value of the underlying state, $\omega_0$. An increase in $\omega_0$ represents an increase in the probability of being caught after defecting. By raising $\omega_0$, a greater proportion of realized signals end up exceeding the $x^*$ threshold, and therefore equilibrium trust is increased:

$$\frac{d\tau^*}{d\omega_0} = \frac{1}{\sigma_0} \cdot \phi\left(\frac{x^* - \omega_0}{\sigma_0}\right) > 0, \tag{17}$$

where $\phi$ is the density of the standard normal distribution. This marginal return is simply the density of the signal noise distribution at $x^*$. Since $x^*$ is decreasing in $s$, we have that the marginal return to legal institutions is increasing in $s$ or $\omega_0$ if and only if this density is downward sloping at $x^*$. This gives us the following.

**Proposition 10.** *Social and legal institutions are complements when such institutions are weak. That is,*

$$\frac{d^2\tau^*}{d\omega_0 ds} > 0 \quad \Leftrightarrow \quad \omega_0 < x^*. \tag{18}$$

The result suggests that there is value in coordinating the development of legal and social institutions: both would be under-provided if not chosen mindful of the positive externality (at least initially when such institutions are weak).

## 4 Conclusion

Trusting someone to take a particular action suggests an expectation that they might not, and that one may therefore be vulnerable to the resulting outcome. We have shown how a funda-

assumptions of the model, then so too will all other elements of $\mathcal{T}$. That is, $\mathcal{T}$ looks just like that given in figure 2(a) where the slope of the line is $1 + \psi \in [1, 2]$.

mental relationship between vulnerability and trust is obscured by the highly convenient and widely adopted assumption that players have common knowledge of the conditions under which their interaction occurs. Specifically, we relax the common knowledge assumption using a 'global games' approach in which players observe private noisy signals of the strength of contract enforceability. In contrast with the common knowledge version, we show how an increase in the payoff to being cheated lowers the critical signal required for cooperation, and thereby increases equilibrium trust. We argue that this relationship is fundamental in the sense that it persists even when trust violations do not occur in equilibrium (i.e. in the limit as signal noise goes to zero).

In order to stress the importance of the common knowledge assumption in obscuring the intuitive relationship between trust and vulnerability, we have intentionally made other aspects of the model as simple as possible. This is not to say that more elaborate versions – perhaps with a more complex production game, heterogeneous players, or repeated interaction – would be uninteresting. We expect the main results to persist in these extensions, but leave this to future research.

Understanding the connection between trust and vulnerability is important for appreciating the role of social institutions in the development process. In addition to the previously identified roles of rectifying market failures for insurance and credit, we show how strong social institutions cultivate a greater willingness to trust by not only softening the consequences of being cheated, but also by providing an added assurance that trading partners will not cheat.

# A Proofs

**Proof of Proposition 1**

*Proof.* Choosing $A_i = D$ is a best response to $A_{-i} = D$ if and only if $u(1) \geq u(s)$, which always holds. Choosing $A_i = C$ is a best response to $A_{-i} = C$ if and only if $u(r) \geq \theta \cdot u(t-F) + (1-\theta) \cdot u(t)$. Simple re-arranging produces the result. □

**Proof of Proposition 2**

*Proof.* The argument in the text establishes that any cut-off equilibrium in which $C$ is played with positive probability must have a cut-off that satisfies (12). The fact that one such $x^*$ exists if and only if $\theta^* < 1$ (noting that $\theta^* \geq 0$) follows from $g$ being a bijection. □

**Proof of Proposition 3**

*Proof.* From (13) and (3), we have that $\tau^*$ is strictly decreasing in $\theta^*$ and $\tau^* = \tau^{**}$ if and only if $\theta^* = \theta^{**}$. From (12) and (2) we have $\theta^* = \theta^{**} + \frac{u(1)-u(s)}{u(t)-u(t-F)} > \theta^{**}$. Therefore $\tau^* < \tau^{**}$. $\square$

**Proof of Proposition 4**

*Proof.* Direct calculation using (12) and (4) with (13) and (5). $\square$

**Proof of Proposition 5**

*Proof.* From (13) and (3), we have $\tau^* = \tau^{**}$ if and only if $\theta^* = \theta^{**}$. From (12) and (2) we have $\frac{d\theta^*}{ds} = \frac{-u'(s)}{u(t)-u(t-F)} \neq \frac{d\theta^{**}}{ds} = 0$. $\square$

**Proof of Proposition 6**

*Proof.* From (13) we have $\frac{d\tau^*}{d\theta^*} = -\frac{1}{\sigma_0}\frac{1}{g'(x^*)}\phi\left(\frac{x^*-\omega_0}{\sigma_0}\right) < 0$. From (12) we have $\frac{d\theta^*}{ds} = \frac{-u'(s)}{u(t)-u(t-F)} < 0$. By the chain rule, $\frac{d\tau^*}{ds} = \frac{d\tau^*}{d\theta^*} \cdot \frac{d\theta^*}{ds}$, which is positive. $\square$

**Proof of Proposition 7**

*Proof.* From (13), the fact that $\frac{d\tau^*}{d\theta^*} \neq 0$, and the chain rule, we have $\frac{\frac{d\tau^*}{ds}}{\frac{d\tau^*}{dr}} = \frac{\frac{d\tau^*}{d\theta^*}\cdot\frac{d\theta^*}{ds}}{\frac{d\tau^*}{d\theta^*}\cdot\frac{d\theta^*}{dr}} = \frac{\frac{d\theta^*}{ds}}{\frac{d\theta^*}{dr}} = \frac{u'(s)}{u'(r)} \geq 1$, being strict when $u'' < 0$. Therefore $\frac{d\tau^*}{ds} \geq \frac{d\tau^*}{dr}$, being strict when $u'' < 0$. $\square$

**Proof of Proposition 8**

*Proof.* Let $\tilde{t}(r; s, \theta, F)$ be the value of $t$ that makes (15) hold with equality. Since the right side of (15) is increasing in $t$, we have that $\mathcal{I} = \{(r,t) \mid t \leq \tilde{t}(r; s, \theta, F)\}$. Since the right side of (15) is decreasing in $s$, we have that $\tilde{t}(r; s, \theta, F)$ is increasing in $s$. Therefore an increase in $s$ expands $\mathcal{I}$ since for each value of $r$, we have more values of $t$ such that $t \leq \tilde{t}(r; s, \theta, F)$. $\square$

**Proof of Proposition 9**

*Proof.* From (16), $\frac{dr^\dagger}{ds} = \frac{1}{\psi} > 0$. $\square$

**Proof of Proposition 10**

*Proof.* From (13), $\frac{d^2\tau^*}{d\omega_0 ds} = \frac{1}{\sigma_0^2}\cdot\phi'\left(\frac{x^*-\omega_0}{\sigma_0}\right)\cdot\frac{1}{g'(x^*)}\cdot\frac{d\theta^*}{ds}$, where $\phi'(\cdot)$ is the derivative of the density of the standard normal distribution. Since $\frac{1}{\sigma_0^2} > 0$, $\frac{1}{g'(x^*)} > 0$, and $\frac{d\theta^*}{ds} < 0$, we have that this is positive if and only if $\phi'\left(\frac{x^*-\omega_0}{\sigma_0}\right) < 0$. But this is true if and only if $\omega_0 < x^*$. $\square$

# B Further Details

Let $\Psi(t \mid \tilde{\omega}_i)$ be the (posterior) distribution of $\theta$ given $i$'s signal:

$$\Psi(t \mid \tilde{\omega}_i) \equiv \Pr[\theta \leq t \mid \tilde{\omega}_i] = \Pr[\omega \leq g^{-1}(t) \mid \tilde{\omega}_i] = \Phi\left(\frac{g^{-1}(t) - \left[\frac{\sigma_0^2}{\sigma_0^2+\sigma^2} \cdot \tilde{\omega}_i + \frac{\sigma^2}{\sigma_0^2+\sigma^2} \cdot \omega_0\right]}{\sigma_1}\right). \tag{19}$$

**Lemma 1.** $\mathbb{E}[\theta \mid \tilde{\omega}_i]$ *is increasing in* $\tilde{\omega}_i$.

*Proof.* We have $\mathbb{E}[\theta \mid \tilde{\omega}_i] \equiv \int t d\Psi(t \mid \tilde{\omega}_i)$. Since $\Psi(t \mid \tilde{\omega}_i)$ is decreasing in $\tilde{\omega}_i$, higher signals produce distributions that first-order stochastically dominate those produced by lower signals. $\square$

**Lemma 2.** $\lim_{\sigma \to 0} \mathbb{E}[\theta| \ x^*] = g(x^*)$

*Proof.* Since $\lim_{\sigma\to 0} \sigma_1 = 0$, we have $\lim_{\sigma \to 0} \Psi(t \mid x^*) = \Psi(\infty) = 1$ if $g^{-1}(t) > x^*$ and $\lim_{\sigma\to 0} \Psi(t \mid x^*) = \Psi(-\infty) = 0$ if $g^{-1}(t) < x^*$. As a result we have $\lim_{\sigma\to 0} \mathbb{E}[\theta| \ x^*] = g(x^*)$. $\square$

**Lemma 3.** *The ex-ante probability of a player being cheated in the 'global games' version of the production subgame goes to zero as signal noise goes to zero.*

*Proof.* Consider a particular realization of $\omega$. The probability that a player is cheated is the probability that the players receive signals on either side of the cut-off. Since there are two players, this probability is

$$\rho(\omega) = 2 \cdot \Phi\left(\frac{x^* - \omega}{\sigma}\right) \cdot \left[1 - \Phi\left(\frac{x^* - \omega}{\sigma}\right)\right]. \tag{20}$$

For $\omega = x^*$ we have $\rho(x^*) = 2 \cdot \frac{1}{2} \cdot \frac{1}{2} = \frac{1}{2}$ for all $\sigma$. For $\omega < x^*$ we have $\lim_{\sigma\to 0} \rho(\omega) = 2 \cdot 0 \cdot 1 = 0$. For $\omega > x^*$ we have $\lim_{\sigma\to 0} \rho(\omega) = 2 \cdot 1 \cdot 0 = 0$. The ex-ante probability of a player being cheated, $\int \rho(\omega) d\Phi\left(\frac{x^*-\omega}{\sigma}\right)$, therefore equals zero. $\square$

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