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ON THE PERSISTENCE OF INEFFICIENT NORMS

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On the Persistence of Inefficient Norms*

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Abstract:

This paper considers an infinite stage two person coordination game in which players are *asymmetrically* informed about the *changes* in the stage-game pay-offs.

The main result is that, in *all* equilibria, if players start by conforming to a stage-game norm then, inspite of the existence of signalling possibilities, the informed player chooses not to signal an interval of strict pareto-improving changes in stage-game pay-offs, and this leads to the persistence of norms, which have become in-efficient.

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1. Introduction.

Akerlof(1980), and in more recent years, Cole, Mailath and Postlewaite (1990), Lal (1988) among others, have constructed formal models which highlight the central role of social conventions and norms in understanding economic growth and efficiency. This work suggests how particular conventions and norms may be detrimental to growth or lead to inefficient outcomes, whereas other norms may fare better. Faced with these results, one is naturally led to ask the following question: How do inefficient norms survive, specially when those who conform to them are aware that these norms are inefficient?

This paper provides an answer to this question in the framework of infinite stage co-ordination games. Incentive conflicts are not at issue in such a framework and this allows us to make our points in a simpler way. In another paper (Goyal and Janssen(1991)), we have explored the problem of learning to co-ordinate in the absence of communication between the players.[1] This work has suggests the need for some extra-individualistic feature in the model to help attain co-ordination in stage-game play. We assume in this paper that, in view of these problems, players may conform to a *stage-game norm* (Definition 2.2, below), which suggests actions, for all stage-games. It is important to note, one, that a stage game norm does not fix an action for each player, but simply *suggests* an action which agents are free to follow or not follow; and two, since this action is related to the specific stage game, it is generally different for different stage games.

We study the persistence of in-efficient norms, by introducing the possibility of a strictly pareto-improving change in the structure of pay-offs of the *stage game.* Both the precise nature of this change and its timing are stochastic. When the change actually occurs it is observed *privately* by the players. We introduce the idea of *signalling* norms (Definition 3.1., below), to facilitate communication of this information, from the informed player to the uninformed player. These signals operate via the pay-offs in the co-ordination game, which are commonly observed.

In this setting we demonstrate (Theorem 1) that, in *any* signalling equilibrium (Definition 3.2) of the infinite stage game, if players start by conforming to stage-game norms, then the informed player, who knows about a strict pareto-improvement in the stage-game pay-offs, chooses *not* to signal this change. This leads to the persistence of norms, which the informed player knows are in-efficient. Theorem 2 shows that there exist such equilibria. The intuition behind Theorem 1 is as follows: In the absence of possibilities of direct communication of change, the only way to signal change in the pay-offs is via the switching of action in the stage game. This could lead to a loss of pay-offs in the stage-game, if the uninformed player in confirming to a norm, plays the action consistent with the previous stage-game. The informed player has to balance this loss against the prospective increase in pay-offs from future stage games. If he discounts future pay-offs, it is possible that for some interval of strictly pareto-improving pay-offs in the stage-game, the sum of discounted pay-offs may be less than the present sacrifice. This would make it optimal for the informed agent to persist with an action that is consistent with initial stage-game norms, but in-efficient.

We also show that this interval of in-efficiency is *monotonically increasing* and *unbounded* in the impatience of players and also in the number of actions of the players, respectively (Propositions 3).

The results in this paper, we believe, provide a new insight into the problem of how in-efficient norms persist in environments with private information. Our paper is closely related, in its motivation, to Akerlof(1976,1980) and Boyer and Orlean(1991). Akerlof considers *static* models, and demonstrates how social norms, such as caste, views about race-worker productivity relationship and fairness are sustained in equilibrium and relate to issues of efficiency and un-employment; in contrast, our paper demonstrates how inefficient stage-game norms may persist in a *dynamic* setting. In addition, Akerlof's results are derived for *large* social settings, in which in-efficient outcomes, once they are in place, are easier to sustain, due to the insignificance of personal initiative; in contrast our results are derived for two agent setings. These two aspects of our model suggest that our results greatly re-enforce the pessimism about decentralized systems that is present in Akerlof's work.

With respect to the Boyer and Orlean(1991), the main difference is in the way that players are modelled; we take players to be rational and optimizing agents, whereas Boyer and Orlean(1991) use an evolutionary model, with agents' choices exogenously determined. The principal result in their paper is that with suitable local interaction structures, strict pareto-improvements if they are feasible can be attained, as evolutionary stable outcomes. In contrast, we show that in environments with asymmetric information and with only two agents, (hence, strictly local interaction, only) in all equilibrium, an interval of strict pareto-improvements is unattainable.

Our main argument is made with the help of a very simple model, which is described in Section 2. Section 3 presents the main results and section 4 considers the robustness of these results. Section 5 concludes.

2. The Model.

In this paper we are concerned with an infinitely 'repeated' version of the following type of a symmetric coordination game.

$$\begin{array}{cc} & \begin{array}{cc} l & r \end{array} \\ \begin{array}{c} l \\ r \end{array} & \begin{pmatrix} (\alpha,\alpha) & (0,0) \\ (0,0) & (\beta,\beta) \end{pmatrix} \end{array}$$

There are two players in the game, the column player and the row player, denoted by C and R, respectively. The set of actions for both players, C and R is $A = \{l, r\}$, and a generic element in this set if denoted by a. The set of mixed strategies for a player is denoted by $\hat{A}$. The pay-offs are given by π_i, where $\pi_i : \hat{A} \times \hat{A} \rightarrow R^l_+$ and $i = CorR$. We are concerned only with strictly symmetric co-ordination games, i.e., for those games where $\pi_i(l,r) = \pi_i(r,l) = 0$, and $\pi_i(l,l) = \alpha > \pi_i(r,r) = \beta > 0$, for $i = CorR$; and hence, without loss of generality, we may simplify the notation and denote pay-offs without a subscript. Denote the generic stage-game by Γ.

Evolution of Pay-offs: A novel feature of our model is the evolution of pay-offs across time. We allow the pay-offs to change over time but retain the co-ordination game structure of the initial game. In particular, we assume that the initial pay-offs are given by $\pi(l,l) = 1 > \pi(r,r) = \beta \geq 0$. Denote this structure by G_0. This is the structure with which players start the infinite stage game. At some point in the course of the game, which is stochastic, the pay-offs can change to α_1 *or* α_2, where $0 < \alpha_2 < \beta < 1 < \alpha_1$. In particular, we consider for simplicity only strictly local changes, and thus the initial stage-game, G_0, may change to any of the following four cases:

(G_1). $\pi(l,l) = \alpha_1$, $\pi(r,r) = \beta$;

(G_2). $\pi(l,l) = \alpha_2$, $\pi(r,r) = \beta$;

(G_3). $\pi(l,l) = 1$, $\pi(r,r) = \alpha_1$;

(G_4). $\pi(l,l) = 1$, $\pi(r.r) = \alpha_2$.

The evolution of the structure of pay-offs over time is defined by a stationary Markov process. The probability of change from G_0 to G_k, for $k \neq 0$, is given by $p > 0$; given a change all the new games, G_k for k=1...4, are equally likely. Also we study the simple case where change occurs but once. These assumptions are represented in a compact way, in the following transition probability matrix.

$$P = \begin{array}{c} \\ G_0 \\ G_1 \\ G_2 \\ G_3 \\ G_4 \end{array} \begin{array}{c} \begin{array}{ccccc} G_0 & G_1 & G_2 & G_3 & G_4 \end{array} \\ \begin{pmatrix} 1-p & p/4 & p/4 & p/4 & p/4 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \end{array}$$

We denote by $G_{t,k}$, the particular structure of pay-offs at stage t and by $G_{t,k}$, the realized evolution of stage-game pay-offs, where k refers to the nature of change and t refers to the point at which the change takes place. The players can compute, for each t, the probability of different G_k. We denote these probabilities derived from P by $\{p_t\} = (p_t^0, p_t^1, p_t^2, p_t^3, p_t^4)$, where p_t^k, denotes the probability of the stage game at point t, being k. This structure of pay-offs implies, in particular, that in the limit the probability of change in the structure of the game is 1. The next issue is the player's information about the changes in the pay-offs.

Information Structure: We assume that one and only one player observes change in the pay-offs, and he does so, if and only if, it actually takes place.[2] In other words, there is no noise in the observation process. This information structure generates asymmetric information in the course of the game and we refer to the informed player as of type I and the uninformed as of type U. More formally, the type set is defined as T, where $T = \{(I_k)_{k=1}^4, U\}$. In the analysis below, however, we use type I to refer to the the generic informed player, for notational simplicity. We can formally state the above assumptions as,

$Prob(One\ player\ is\ of\ type\ I\ at\ \hat{t}/change\ at\ stage\ \hat{t}) = 1,$

$Prob(C\ or\ R\ observe\ change\ at\ stage\ k \neq \hat{t}/change\ at\ stage\ \hat{t}) = 0.$

The evolution of beliefs of a player who is of type I is then straightforward. How do the beliefs of the type U player evolve? This depends on the game until a particular stage, and to understand it we turn to a description of history.

History: We assume that at the *begining* of a stage game, players have a chance to observe the move of nature and then at the *end* of each stage the players recall their own action and can observe only the pay-offs. The motivation for this assumption is that in a variety of settings, such as co-ordinated action in battles, actions are not observable but outcomes are observable. This assumption does not play an important role in the 2 action case, but is crucial for results in a more general action space (see Proposition 4, below).

The time line for a specific t stage game may be represented as follows: $t(0)$: nature moves; $t(1)$: one player observes outcome; $t(2)$: updating of beliefs by players; $t(3)$: players make their moves; $t(4)$: the pay-offs accrue to the players; $t(5)$: players update their beliefs about the pay-offs structure. End of stage t game. In particular then, players may learn, about the structure of the stage-game, from the move of nature and the pay-offs that result. We shall specify how this updating take place in more detail below.

At any stage a player can recall perfectly all his own past actions, and all past pay-offs. History at stage t is thus a sequence, $h_i^{t-1} = (\{a_{i,1}, \pi_1\}, ..., \{a_{i,(t-1)}, \pi_{t-1}\})$ and $h_i^{t-1} \in H^{t-1}$. We next describe how this history is incorporated in the evolution of player's beliefs over time.

Beliefs: We model players as Bayesian agents in the sense that they have beliefs, in the form of probability distributions, about the stage-game they are playing, and use Bayes' Rule to update these beliefs on receiving relevant information concerning these unknowns. We denote beliefs at stage $t(0)$ for player i, by $b_{i,t}$, where $b_{i,t} = \{(\mu_{i,t}^0) : \sum_{k=0}^4 \mu_{i,t}^k = 1\}$. Here $\mu_{i,t}^k$ represents the probability mass assigned to stage-game G_k. Denote the set of possible beliefs by B.

At stage 1, all players know the stage-game is G_0, that subsequently the game may change, and that they may not observe the change. Thus players enter with prior belief about the true stage-game, b_0 which assigns full probability mass to G_0, i.e., $\mu_{i,0}^0 = 1, \forall\, i$. A player's beliefs evolve in the course of the game, as a function of the stochastic process defined above, (as represented in the transition matrix P), his/her possible observation of nature's move, and past pay-offs, h_i^t. $b_{i,t}$ are derived from prior beliefs $b_{i,0}$, given the type, T_i and history, h^t using Bayes' Rule, and may formally be defined as,

$$b_{i,t} : P \times T \times H^{t-1} \rightarrow B$$

Recall that updated beliefs, $b_{i,\hat{t}}$ are constituted of $\{\mu_{i,t}^k\}_{k=0}^4$. As an illustration, for the updating procedure, we consider the situation where a player *knows* that his opponent's strategy is specified as follows: For $T = U$, $s_{i,t}\ (U, h_i^{t-1}) = l, \forall h_i^{t-1}$; and for $T = I$, $\forall h_i^{t-1}$, $s_{i,t}(I, h_i^{t-1}) = r$, only if $G_{t,k} = G_3$ and $s_{i,t}\ (I, h_i^{t-1}) = l$, otherwise. Suppose that at stage $\hat{t}$,

$\hat{h}_i^{\hat{t}-1} = (\forall\ t < \hat{t}, s_t = l; \forall t < (\hat{t}-1), \pi_t = 1, \pi_{\hat{t}-1} = 0)$

and type of player i, $T_{i,\hat{t}} = U$, then we derive $\mu_{i,t}^k$, as follows:

$\mu_{i,t}^k(U, \hat{h}_i^{\hat{t}-1}) = Prob(G_{\hat{t},f} = G_k/U, \hat{h}_i^{\hat{t}-1})$

$= \frac{Prob(U,\hat{h}_i^{\hat{t}-1}/G_{\hat{t},f}=G_k).\mu_{i,\hat{t}-1}^k}{\sum_{k=0}^4 Prob(U,\hat{h}_i^{\hat{t}-1}/G_{\hat{t},f}=G_k).\mu_{i,\hat{t}-1}^k}$

Given the strategy being followed by his opponent, and the history observed, a player can calculate that $Prob(U, \hat{h}^{\hat{t}-1}/G_{\hat{t},f} = G_k) = 0$, for $k = 0, 1, 2$ *or* 4. Hence, $\mu_{i,\hat{t}}^k(U, \hat{h}_i^{\hat{t}}) = 0$, for $k = 0, 1, 2,$ *or* 4, and $\mu_{i,\hat{t}}^3(U, \hat{h}_i^{\hat{t}}) = 1$.

We also denote by $b_i = (b_{i,t})_{t=1}^{\infty}$, the beliefs of player i, in the infinite stage game.

Strategies: For the stage-game the strategies are denoted by $s_{i,t}$, and defined as a mapping, $s_{i,t} : T \times H^{t-1} \to \hat{A}$. Also the behaviour strategy for player i, in the infinite stage game is defined as an infinite sequence of such stage-game mappings, and denoted by s_i, for player i, i.e., $s_i = (s_{i,t})_{t=1}^{\infty}$; and $s_t = (s_{C,t}, s_{R,t})$.

The expected pay-offs in the stage-game are denoted by $X_{i,t}(s_C, s_R/b_{i,t})$ where, $X_{i,t}(s_C, s_R /b_{i,t}) = Prob(s_{C,t} = s_{R,t} = l)(\mu_{i,t}^0 + \mu_{i,t}^1.\alpha_1 + \mu_{i,t}^2.\alpha_2 + \mu_{i,t}^3 + \mu_{i,t}^4) + Prob(s_{C,t} = s_{R,t} = r)(\mu_{i,t}^0 + \mu_{i,t}^1\beta + \mu_{i,t}^2\beta + \mu_{i,t}^3.\alpha_1 + \mu_{i,t}^4.\alpha_2)$.

The expected pay-offs in the infinite stage game is defined as a sum of the expected pay-offs from the stage-games, and denoted by,

$$X_i^{\infty}(s_C, s_R) = \sum_{t=1}^{\infty} \delta^t X_t[s_{C,t}, s_{R,t}/b_{i,t}]\ for\ i = C, R$$

We define an equilibrium concept, incorporating the idea of sequential rationality, as follows:

Definition 2.1: Equilibrium: *An equilibrium is a strategies and beliefs pair,* $\{\hat{s}_t, \hat{b}_t\}_{t=1}^{\infty}$, *s.t.,* *1. For any $h_i^{t'}, T_{i,t'}$,*

$$\sum_{t=t'}^{\infty} \delta^{t-t'} X_t[\hat{s}_{i,t}, \hat{s}_{-i,t}/\hat{b}_{i,t}] \geq \sum_{t=t'}^{\infty} \delta^{t-t'} X_t[a, \hat{s}_{-i,t}/\hat{b}_{i,t}], \forall a \in A^{/t}$$

Here $A^{/t}$ represents the set of actions after stage (t-1).

2. The beliefs, $\hat{b}_{i,t'}$ are derived as follows:

For $T_{i,t'} = I$, $\hat{b}_{i,t'}$ is s.t., $\mu_{i,t'}^k = 1$, for the k representing the observed new game.

For $T_{i,t'} = U$, $\hat{b}_{i,t'}$ depends on the transition matrix P, and the history, $h_i^{t'-1}$. In particular,

(i). $\forall h_i^{t'-1}$, which occurs with strictly positive probability, given (s_C, s_R), $\hat{b}_{i,t}$ are derived using Bayes' Rule.

(ii). $\forall h_i^{t'-1}$, where Bayes Rule is inapplicable, if for some $t \leq t'$, $\pi_t(.) = \alpha_1$ or α_2, then $\hat{b}_{i,t'}$, is s.t., $\mu_{i,t'}^k = 1$, for the corresponding G_k; and otherwise, all beliefs $b_{i,t} \in B$, are admissable.

In the analysis below for simplicity we will consider only equilibrium in pure-strategies. Our focus is the persistence of in-efficient stage-game norms, in equilibrium. To facilitate the statement of results, we formally define stage-game norms and persistence of inefficient norms.

As a motivation for the definition recall the well known example of which side of the road to drive on; the norm in France suggests that you should drive on the right side of the road, whereas if you were in England, then the norm suggests that you should drive on the left side of the road. Thus a stage-game norm suggests actions for each player in a stage-game. We consider a class of stage-game norms with two properties: (i). For every mutually known stage-game the norm specifies a particular pair of actions; (ii). For stage-games not mutually known, it suugests that players choose actions that are the same as the actions in the last mutually known stage-game. (Formally, a fact is mutual knowledge, if $\forall i$, player i knows that it is true and also knows that player $-i$ knows that it is true.) This is a natural set of norms; examples include contingent plans in battles, and statements in bilateral agreements which say " both parties agree to do 'x' unless mutually informed about a new contingency". In the analysis below, for expositional simplicity, we consider a particular member of this class of norms: Our stage-game norm suggests pareto-efficient actions in *mutually known* stage-games. It is easily verified that our results carry over to the more general class of norms outlined above. Formally,

Definition 2.2: Stage-Game Norms. *A stage-game norm suggests that: (a). When G_0, G_1, or G_4, is mutually known to be the true stage-game, then both players should play l and when the true stage game is mutually known to be G_2 or G_3, then players should play r; (b) For stage-games which are not mutually known, players choose the same action as in the last mutually known stage-game.*

We say that players conform to a norm when they take actions recommended by the norm, and define in-efficiency of stage-game norms, using an expost notion, as follows:

Definition 2.3: In-efficient Stage-game Norms. *A stage-game norm is said to be in-efficient if in equilibrium play, in a stage-game in which players conform to it, the stage-game outcome is pareto in-efficient.*

This leads us to a definition of persistence of in-efficient stage-game norms, as a property of equilibria of the infinite stage game.

Definition 2.4: Persistence of In-efficient Norms. *An equilibrium has the persistence of in-efficient norms property if, players conform to the stage-game norm forever, despite it being in-efficient from some point onward with strictly positive probability.*

3. Analysis.

In this section we analyze the implications of allowing norms to play a role in the decision making of rational individual agents in a strategic setting. The principal result (Theorem 1) is that if, $\alpha_1 \in (1, \frac{1}{\delta})$, then in *all* signalling equilibria (see Definition 3.2, below), in which players start by conforming to stage-game norms, they persist with playing l, forever, when the true stage-game is G_3 after some point. (By *start by conforming* we mean that players conform to the stage-game norm in the first stage-game.) Theorem 2 shows that there exist signalling equilibria in which players start by conforming to the stage-game norm.

Our first set of results (Propositions 1,2) pertain to the extent of learning of the true stage-game. Recall, from assumptions above that, when it occurs, one player always observes the change in the game. Thus the issue is: Does the type U player also learn that the game has changed?

The first result answers the above question in the affirmative, by showing that even in the absence of any learning via pay-offs, since the posterior beliefs of players evolve over time, as a natural consequence of the probability structure of change assumed above, in the long run type U too is certain that the stage-game has changed. This observation is formally stated as follows.

Proposition 1: *Suppose that players choose action l, for ever; then, the sequence of posterior beliefs about G_0, $\{\mu_t^{0'}\} \rightarrow \mu^0 = 0$.*

Proof: This is a direct consequence of the consistency of Bayesian posteriors.

Our second observation shows that players do not necessarily learn the true stage-game. In particular, we show that there exists an equilibrium in which the type U player does not learn the *true* stage game, even in the long run.

Proposition 2: *There exists an equilibrium, in which players start by conforming to the stage game norms and the uninformed player never learns the true game being played.*

Proof: *(Sketch)* Consider the following strategy-beliefs pair: $\forall T$, *and* $\forall h_i^{t'-1}$, s.t., $h_{i,t \leq t'-1}$ $= (l, 1 \text{ } or \text{ } \alpha_1) \text{ } or \text{ } (r, \alpha_2)$, $s_{i,t} = l$; and $\forall T, \forall h_i^{t'-1}$, s.t., for some $t < t'$, $h_{i,t} = (l, \alpha_2) \text{ } or \text{ } (r, \alpha_1)$, $s_{i,t} = r$, $\forall t \geq t'$, and $i = C, R$. The beliefs, $b_{i,t}$ are derived using Bayes' Rule for all histories which, given $\hat{s}$ occur with positive probability, and for histories which have for t a component $(l, \alpha_1 \text{ } or \text{ } \alpha_2), (r, \alpha_1 \text{ } or \text{ } \alpha_2)$, the beliefs correspond to the true state game, then. Finally, for all other histories which occur with zero probability, given $\hat{s}$, all beliefs $b \in B$ are admissable. It is easily checked that this is an equilibrium of the infinite stage-game, and that in it players start by conforming to stage-game norms. However, note that there is no learning of the true stage game, along the equilibrium path, if the stage game after period $\hat{t}$ is G_3 or G_4. **Q.E.D.**

Our principal concern is with the persistence of in-efficient norms and so from now on we will focus on the case where the realized change is G_3. In this context, the following corollary is an immediate consequence of the above proposition.

Corollary: *There exists an equilibrium in which players choose to play l forever, despite $G_{t,k} = G_3$, $\forall t \geq \hat{t}$.*

The corollary demonstrates that it is quite easy for a stage-game norm, once in place, to persist inspite of some player knowing that it is in-efficient. This result may be seen as an analogue to the results on persistence of in-efficient norms. derived by derived by

Akerlof(1980), in a static setting. Unlike in his results, however, in our setting social sanctions are not necessary, to sustain the norm.

The equilibrium constructed in Proposition 2 points to the *static* nature of the norm defined above as a possible cause of this in-efficiency. The stage-game norm does not say anything about what action to choose when the opponent has played r, and this creates the following problem: An informed player does not have an incentive to signal when the uninformed player is not ready to receive the signal (Crawford and Sobel(1982)). We introduce the notion of signalling norms to overcome this problem.

As a motivation for signalling norms, recall the homely example: What does a person infer when suddenly one morning he observes that all motorists are driving on the wrong (say the right) side of the main road? He might think that everyone has made a mistake, but it is more likely that he thinks that, they must have some good reason to do so, i.e., the structure of the pay-offs has altered.....

The following definition of signalling norms is introduced to take account of this reasoning in the face of knowledge that the world is changing and this change is imperfectly observed.

Definition 3.1: Signalling Norms. *A signalling norm specifies, for a player who has not switched actions;*

(i). A rule to modify beliefs, about the true stage-game being played, when an opponent first takes an action inconsistent with initial stage-game norms; and

(ii). Beliefs about opponent's actions in the event that opponent does not observe any move by nature; in particular, a player, after a history when no one has switched, believes that his opponent will switch first only if he (the opponent) observes a change in stage-game pay-offs.

Note that part (ii) in the definition above is needed for part (i) to be useful as a norm about signals. If the opponent can switch randomly or experimentally then the switch in action will cease to be a signal.[2]

As an application of signalling norms, we consider the case where a player of type U, who has not observed nature change the game to G_3, observes that the pay-offs in a particular stage game are 0. Given that he himself has not chosen r, he updates the belief about the other player's action in the direction of assuming that there must be a good reason for the player to switch suddenly to playing r, which given the structure of the model, must lie in the change in stage-game pay-offs. Thus he comes to believe that the game must be G_2 or G_3. This intuition is similar to the idea present in van Damme's definition of equilibrium consistent with forward induction (see Fudenberg and Tirole(1991), Definition 11.8, p.464); however, we do not formally develop this idea further, as this is not the focus of the present paper.

For example, we say that equilibrium beliefs satisfy signalling norms if the following is true:

For $T_{i,t'} = U$, $\forall h_i^{t'-1}$, *s.t.,* $\forall t \leq (t'-1), h_{i,t} = (l,1)$, *and* $h_{i,t'-1} = (l,0)$, $b_{i,t'} = \{\mu_{i,t'} : \mu_{i,t'}^2 + \mu_{i,t'}^3 = 1\}$.

Signalling norms thus restrict beliefs off the equilibrium path, and the above specification has the important effect of eliminating certain equilibria, on grounds of sequential rationality. For instance, in the equilibrium used in the proof of Proposition 2, type I player will, for sufficiently high values of α_1, certainly find it more profitable to switch and thus signal a change of the game to G_3, given that type U player interprets this as a signal for a change in the stage-game. The type I player will note that such a switch involves a loss of one period pay-offs in the present stage-game, but possibly a substantial increase in all subsequent pay-offs, since the type U player, on observing the 0 pay-offs will, following on the signalling norm, infer that the game has changed and the new game is given by G_2 or G_3. Hence he will play r too, as this is the optimal response to a belief about type I player's action in these two stage-games.

But does this signalling norm eliminate in-efficient stage game play and hence in-efficient norms? The answer is, No. The reason for this is that for an interval of values of α_1 higher than but close to 1, the type I player has inadequate incentives, given that $\delta < 1$, to switch. We show that this interval is non-empty for all equilibria in which player's abide by signalling norms.

We refer to an equilibrium in which players play in conformity with signalling-norms as a signalling equilibrium. Formally,

Definition 3.2: Signalling Equilibrium. *An equilibrium* $(\hat{s}, \hat{b})$ *is called a signalling equilibrium, if and only if, the strategies,* $(\hat{s})$ *and beliefs,* $(\hat{b})$ *are consistent with signalling norms.*

We can now state our main result.

Theorem 1: *Suppose $1 < \alpha_1 < \frac{1}{\delta}$. Any signalling equilibrium, in which players start by conforming to the stage-game norm, has the persistence of in-efficient norms property.*

Proof: This is a claim about equilibria in which players start by conforming to the stage-game norms, and in addition, also conform to signalling norms. In any such equilibrium, for the claim to be true, it suffices to show that if $1 < \alpha_1 < \frac{1}{\delta}$ then if $G_{t,k} = G_3, \forall t \geq \hat{t}$, players do not switch actions and continue playing l forever. Given the hypothesis that an equilibrium satisfies signalling norms, any such switch must be initiated by the type I player. Thus, we only have to check if type I player has the incentive to switch.

In a signalling equilibrium, the player of type I knows that unless he switches to r both players will continue playing l, forever. Observe that switching is better than never switching if pay-off from switching now, $X_{sn}^{\infty}(I)$, or pay-off from switching after n periods, $X_{n}^{\infty}(I)$, is greater than the pay-off from never switching, $X_{ns}^{\infty}(I)$. We compare these cases below.

$X_{ns}^{\infty}(I) = \frac{1}{1-\delta}$; $X_{n}^{\infty}(I) = \frac{1-\delta^{n-1}}{1-\delta} + \frac{\delta^{n}.\alpha_1}{1-\delta}$; $X_{sn}^{\infty}(I) = \frac{\delta.\alpha_1}{1-\delta}$;

After simplification, these expressions show that, $X_{sn}^{\infty}(I) \geq X_{ns}^{\infty}(I)$, only if, $\alpha_1 \geq \frac{1}{\delta}$. Likewise, it is easy to show that $X_{n}^{\infty}(I) \geq X_{ns}^{\infty}(I)$, only if, $\alpha_1 \geq \frac{1}{\delta}$. **Q.E.D.**

Remark: This result can be extended to the case where both players can privately observe the change in the true stage-game, with strictly positive probability.

This shows that in any signalling equilibrium, if players start by conforming to stage-game norms, then there exists an interval of possible strict pareto-improvements which are not exploited as the informed player has an incentive to *not* switch. Moreover, it is immediate that this interval of in-efficiency is increasing and unbounded as the players get more impatient.

The role of asymmetric information is crucial here, because if there were mutual knowledge of the new stage-game, conformity to stage-game norms would be sufficient to erode old norms and thus eliminate inefficiency of the sort identified above.

We conclude this section by showing that there exist such equilibria.

Theorem 2: *There exists a signalling equilibrium in which players start by conforming with stage-game norms.*

Proof: Consider the symmetric strategy belief profile, $(\hat{s}, \hat{b})$: where

$((\hat{s}_{i,t})_{t=1}^{\infty}$, is s.t.,

$\hat{s}_{i,1} = l$, for $i = C$ *and* R.

For $T_{i,t} = U$, (i). $\forall h_i^{t'-1}$, s.t., if for any $t \leq t'$, $h_{i,t} = (r, \alpha_1)$, *or* (l, α_2), then $\hat{s}_{i,t'} = r$; and if $h_{i,t} = (l, \alpha_1)$, *or* (r, α_2), then $\hat{s}_{i,t'} = l$; (ii). $\forall h_i^{t'-1}$, s.t., $\forall t \leq t'-1$, $h_{i,t} = (l, 1)$, $\hat{s}_{i,t'} = l$; (iii). $\forall h_i^{t'-1}$ not in case (i), and , s.t., $\forall t < \hat{t} < t'$, $h_{i,t} = (l, 1)$, and $h_{i,\hat{t}} = (l, 0)$, $\hat{s}_{i,t'} = r$; (iv). $\forall h_i^{t'-1}$ not in case (i), and, s.t., $\forall t < \hat{t} < t'$, $h_{i,t} = (l, 1), h_{i,\hat{t}} = (r, 0\ or \beta)$, $\hat{s}_{i,t'} = r$; (v). $\forall h_i^{t'-1}$ not in case (i), and s.t., $h_{i,1} = (l, 0)$ *or* $(r, 0$ *or* $\beta)$, $\hat{s}_{i,t'} = r$.

For $T_{i,t'} = I$, the strategies for each of the above five classes of histories, are as follows:

(i), (iii)-(v), are the same as for $T_{i,t'} = U$, above; (ii). $\forall h_i^{t'-1}$, s.t., $\forall t < t'$, $h_{i,t} = (l, 1)$, then if $T_{i,t'} = I_3$, then $\hat{s}_{i,t'} = r$, if $\alpha_1 \geq \frac{1}{\delta}$, and $\hat{s}_{i,t'} = l$, if $\alpha_1 < \frac{1}{\delta}$; also if $T_{i,t'} = I_1, I_2$ *or*, I_4, then $\hat{s}_{i,t'} = l$.

The beliefs, $\hat{b}_{i,t}$, are derived as follows: For all histories, $h_i^{t'-1}$ that occur with positive probability, given $\hat{s}$, above, $\hat{b}_{i,t}$ are derived using Bayes' Rule. For those histories which, given $\hat{s}$, obtain with zero probability, if $h_i^{t'-1}$, is s.t., $h_{i,t} = (l, 1), \forall t < t'-1$, and $h_{i,t'-1} = (l, 0)$, then $\{\mu_{i,t'}^2(U) + \mu_{i,t'}^3(U) = 1\}$; and $\forall h_i^{t'-1}$ in class (i) above, $\mu_{i,t'}^k = 1$, for the corresponding G_k, whose pay-offs were observed. For all other histories, which are observed with zero probability, given $\hat{s}$, any belief $b \in B$, is admissable. It is possible to show that this strategy-beliefs pair constitutes an equilibrium, satisfies signalling norms and that players start by conforming to stage-game norms. Details are given in the appendix. **Q.E.D.**

4. Extensions.

Are the above results robust? In this section, we examine how this interval of inefficiency, $1 < \alpha_1 < \frac{1}{\delta}$, is related to the parameters of the model. In particular, we look at the role of the number of actions.

Number of Actions: The results in the previous sections have been proved for the case when there are only two possible actions in each stage game; l and r. It is possible to generalize the results to a more general action space, say with N actions. G_0 has the structure, $\pi(l) = 1$, and $\pi(r_j) = \beta < 1, \forall j = 1, 2 ... (N-1)$. Each of the $\pi(a)$ can change to one of α_1 or α_2, and as before, $0 < \alpha_2 < \beta < 1 < \alpha_1$; G_1 and G_2 are defined as in section 2 above, and account for local changes for $\pi(l)$ to α_1 or α_2. The structure of the new stage-games corresponding to G_3 and G_4, can then be represented as follows,

$G_{3,j} = \{\pi(l) = 1; \pi(r_j) = \alpha_1; \pi(r_{i \neq j}) = \beta\};$

$G_{4,j} = \{\pi(l) = 1; \pi(r_j) = \alpha_2; \pi(r_{i \neq j}) = \beta\}.$

Furthermore, we retain the Markov structure of the evolution of the pay-offs over time. In particular, the probability of change at any point is $0 < p < 1$, and each of the $2n$ new stage-games have an equal probability, $\frac{p}{2n}$ of occuring.

Given the signalling of type I player, there are several ways in which the type U player may search for the new optimal point. We focus on two relatively straightforward strategies: Equi-Probability Randomized search and Deterministic search. Moreover, in equilibrium, the type I player can, after he has signalled change in stage-game, choose to co-ordinate or not to co-ordinate with the search strategy of the type U player. It is possible to show that if type U player is playing an equi-probability randomized (deterministic) search strategy, then the best response of the type I player must be to persist with the new optimal action r_j (choose actions in a co-ordinated way). So in the proposition below we focus on the cases: Uncoordinated randomized search and deterministic coordinated search.

An interesting consequence of expanding the action set is that the interval of in-efficiency for all signalling equilibria expands. It is shown below that this interval is unbounded as the set of actions grows. In particular, if we denote the number of actions in the set A_i by N, the interval of in-efficiency, for a signalling equilibrium, by $Z(N)$, the supremum of this interval by $Z^s(N)$, then as N gets large, $Z^s(N)$ is unbounded. The intuition behind the result is that, as the number of actions gets large, the time taken to discover the true location of change, for the U type player grows, and hence the prospect of losses for the type I player in the interim, grows as well, thus discouraging any switching by the type I player.

Proposition 3: *In any signalling equilibrium. if players start by conforming to stage-game norms and if type U player uses an equi-probability randomized search process or the deterministic search process, then* $lim_{N \to \infty} Z^s(N) \to \infty$.

Proof: See appendix.

5. Conclusions.

Formal analysis of norms as devices for co-ordinating expectations, by Akerlof and others, suggests that such social arrangements may sustain outcomes which are pareto inefficient. A natural question arises: Why do these norms persist inspite of agents knowing their inefficiency?

We provide an explanation for this phenomena, in a dynamic context. It is shown that in all equilibria of an infinite stage game, if players start by conforming to a stage-game norm then, inspite of the existence of signalling norms, the informed player, who knows about a strict pareto-improvement in the stage-game pay-offs, chooses not to signal this change. This leads to players persisting with initial stage-game norms inspite of their in-efficiency.

The framework developed here is, we believe also quite appropriate for understanding one of the fundamental issues in the economics of organization (Arrow 1972); viz., the optimal design of information transmission systems. Our results on the in-efficiency of norms, in particular, point to the need for investigating the nature of ex-ante optimal organization design in the presence of environmental uncertainty.

Notes.

(1). Crawford and Haller(1990), study the problem of optimal learning rules for coordination, in the absence of common labelling of the stage-game. There are several optimal rules in their model, and, in our view, this suggests the need for some form of communication norms, to sustain *their* choice of an optimal rule.

(2). More complicated signalling and coordination norms are possible, in which experimentation by players about the true stage-game is allowed, and also co-ordinated. Generally such norms are of little relevance, due to the large transition costs associated with regime switching; besides in our framework, given the pareto ranking of pay-offs in the stage-game, such norms will involve direct losses.

Appendix:

Proof of Theorem 2: First, it is shown that the pair, $(\hat{s}, \hat{b})$, constitutes an equilibrium; next we prove that it satisfies signalling norms and players start by conforming to the stage-game norms.

The proof for existence is done in two steps; one, it is shown that $\forall h_i^{t'}$ and for all $T_{i,t'}$, given $\hat{s}_{-i}$ and beliefs, $\hat{b}_i$, $\hat{s}_i$ is the optimal strategy for player i; then it is shown that $\hat{b}$ satisfy the requirements in the definition of equilibrium.

There are two types of players and five classes of histories; $\hat{s}$ must be optimal for each of these cases.

We first consider the case where $T_{i,t'} = U$,

(i). $\forall h_i^{t'}$, s.t., for some $t \leq (t'-1)$, $h_{i,t} = (l, \alpha_1)$, or (r, α_2), given $\hat{s}_{-i}$, $\forall t \geq t'$, $s_{-i,t} = l$, and it it is immediate that $\forall t \geq t', \hat{s}_{i,t} = l$ attains the maximum attainable pay-off and hence is the best response. Analogous arguments can be made for the optimality of of $\hat{s}_i$, in case of $h_i^{t'}$, s.t., for some $t \leq t'-1$, $h_{i,t} = (l, \alpha_2)$, or (r, α_1).

(ii). Given opponent strategy $\hat{s}_{-i}$, denote the pay-off from a strategy which involves switching now, by X_{sn}^{∞}. This pay-off can also be written as follows: $X_{sn}^{\infty} = Prob(T_{-i,t'} = I)X_{sn}^{\infty}(T_{-i,t'} = I) + Prob(T_{-i,t'} = U)X_{sn}^{\infty}(T_{-i,t'} = U)$, where the latter two pay-offs refer to the cases where player $-i$ is of type I or type U, respectively. We consider the case where $\alpha_1 \geq \frac{1}{\delta}$. This is the harder case to prove, but a similar argument works for $\alpha_1 < \frac{1}{\delta}$.

The proof consists of showing that irrespective of the actual type of the other player, at stage t', given his strategy $\hat{s}_{-i}$, it is optimal for player i, of type U, to follow $\hat{s}_i$, after a history in class (ii).

Denote the pay-off from following $\hat{s}_i$, as a response to $\hat{s}_{-i}$, given that the opponent is of type I, by $X_{\hat{s}}^{\infty}(T_{-i,t'} = I)$. $X_{sn}^{\infty}(T_{-i} = I) \leq \frac{1}{4}(\frac{\delta.\beta}{1-\delta} + \frac{\delta.\beta}{1-\delta} + \frac{\alpha_1}{1-\delta} + \delta.\alpha_2 + \frac{\delta^2.1}{1-\delta})$, since the expresion on the r.h.s. is the maximum pay-off possible after playing r at stage t', given $\hat{s}_{-i}$. Denote by $X_{\hat{s}}^{\infty}(T_{-i,t'} = I)$ the pay-off from playing $\hat{s}_i$. $X_{\hat{s}}^{\infty}(T_{-i,t'} = I) = \frac{1}{4}(\frac{\alpha_1}{1-\delta} + \alpha_2 + \frac{\delta.\beta}{1-\delta} + \frac{\delta.\alpha_1}{1-\delta} + \frac{1}{1-\delta})$. It is checked easily that $X_{sn}^{\infty}(T_{-i,t'} = I) \geq X_{\hat{s}}^{\infty}(T_{-i,t'} = I)$ only if, $\alpha_2(1-\delta)^2 + \delta.\alpha_1 + 1 - \delta.\beta - \delta^2 \leq 0$. Since this is never true, $X_{sn}^{\infty}(T_{-i,t'} = I) < X_{\hat{s}}^{\infty}(T_{-i,t'} = I)$

Next consider the case where the opponent too is of type U, and denote the pay-off from following $\hat{s}_i$, given $\hat{s}_{-i}$, by $X_{\hat{s}}^{\infty}(T_{-i,t'} = U)$. W.l.o.g., consider any particular time period of change, of the true stage-game, and fix this period of change as $\hat{t}$. It can be shown that, for any such period of change of the stage game,

$$X_{sn}^{\infty}(T_{-i,t'} = U)(\hat{t}) \leq \delta.\beta + ... + \delta^{\hat{t}-1}.\beta + \frac{1}{4}(\frac{\beta}{1-\delta} + \frac{\beta}{1-\delta} + \frac{\alpha_1}{1-\delta} + \alpha_2 + \frac{\delta}{1-\delta}),$$

since the expression on the r.h.s., is the maximum pay-off possible, after $s_{i,t'} = r$, given that opponent is playing $\hat{s}_{-i}$. Likewise, it is possible to calculate the pay-off from following $\hat{s}_i$, and,

$X_{\hat{s}}^{\infty}(T_{-i,t'} = U)(\hat{t}), = 1 + \delta + ...\delta^{\hat{t}-1} + \frac{1}{4}(\frac{\alpha_1}{1-\delta} + \alpha_2 + \frac{\delta.\beta}{1-\delta} + \frac{\delta.\alpha_1}{1-\delta} + \frac{1}{1-\delta})$

It is easy to check that $X_{sn}^{\infty}(T_{-i,t'} = U)(\hat{t}) \geq X_{\hat{s}}^{\infty}(T_{-i,t'} = U)(\hat{t})$, only if $(1-\delta)\beta + \beta + \delta \geq \delta.\alpha_1 + 1$, which is impossible. Since this is true for any $\hat{t} > t'$, it is also true for the expected value over all $\hat{t} \geq t'$, i.e., $X_{sn}^{\infty}(T_{-i,t'} = U) < X_{\hat{s}}^{\infty}(T_{-i,t'} = U)$.

Putting together the two cases examined above proves that $X_{\hat{s}_i}^{\infty} \geq X_{sn}^{\infty}$, and this completes the argument for optimality of $\hat{s}_i$ after class (ii) histories.

(iii). For all such $h_i^{t'}$, it must be true that $h_{-i,\hat{t}} = (r, 0)$, and given $\hat{s}_{-i}$, irrespective of the type of the opponent, $s_{-i,t'} = r$, and also $\forall h_i^{t'}$ not in class (i), $\forall t \geq t'$, $s_{-i,t} = r$. There are four cases to consider, $G_{t,k} = G_{(1,2,3,\ or\ 4)}$. Given $\hat{s}_{-i}$, it is immediate that for $G_{t,k} = G_{(2\ or\ 3)}$, $s_{i,t} = r$ is optimal. If $G_{t,k} = G_1$, then given $\hat{s}_{-i}$, the maximum possible pay-off is $\frac{\beta}{1-\delta}$, and $\hat{s}_i$ attains it, thus it is optimal. Finally, if $G_{t,k} = G_4$, then maximum attainable pay-off for player i, given $\hat{s}_{-i}$, is equal to $\alpha_2 + \delta\frac{1}{1-\delta}$. which is attained by $\hat{s}_i$. This establishes the optimality of $\hat{s}_i$, after class (iii) histories.

(iv). For these histories, it must be true that $h_{-i,\hat{t}} = (l, 0)$. This implies that irrespective of the type, $s_{-i,t'} = r$, and furthermore, $\forall h_{-i,t>t'}$, (save histories in class (i)), $s_{i,t} = r$; hence, for type U, $\hat{s}_i$, is optimal using exactly the same arguments as in case (iii) above.

(v). For such histories there is a mirror image in class (v) for the opponent, and since for any evolution in the future, except the case of histories that lead to case (i), $\forall t > 1$, $\hat{s}_{-i,t} = r$, the optimality of $\hat{s}_i$, is immediate, (given case (i) above).

We now consider the case, $T_{i,t'} = I$,

For cases (i), (iii), (iv) and (v), arguments sketched above can be used to demonstrate optimality. Case (ii) is different and proved as follows.

(ii). For such histories, $\forall t \leq t' - 1$, $h_{-i,t} = (l, 1)$, and given $\hat{s}_{-i,t'} = l$, and case (ii) and case (iii) above, for $T_{i,t'} = U$, in case of $T_{i,t'} = I_3$, the pay-off is given by $X_{sn}^{\infty}(I) = \delta.\frac{\alpha_1}{1-\delta}$; the pay-off from switching n periods later is given by $X_n^{\infty}(I) = \frac{1-\delta^{n-1}}{1-\delta} + \frac{\delta^n.\alpha_1}{1-\delta}$; and pay-off from never switching is given by $X_{ns}^{\infty}(I) = \frac{1}{1-\delta}$. Given $\hat{s}_{-i}$, it follows that $s_{i,t'} = r$ is better if and only if, $\alpha_1 \geq \frac{1}{\delta}$. For the case $T_{i,t'} = I_1$, or I_4, given case (ii) above, $\forall t \geq t', \hat{s}_{-i,t} = l$, and so $\hat{s}_i$ attains the maximum pay-off, $\frac{\alpha_1}{1-\delta}$, or $\frac{1}{1-\delta}$, depending on the true stage-game. If $T_{i,t'} = I_2$, given $\hat{s}_{-i}$, for case (i), and that $\alpha_2 > 0$, the highest pay-off possible is $\alpha_2 + \frac{\delta.\beta}{1-\delta}$, and since $s_{i,t'} = l$ attains this pay-off, it is optimal.

Next we show that beliefs are consistent with rules specified in the equilibrium definition:

Note that for all histories that occur with positive probability, the beliefs, $\hat{b}_{i,t}$, are updated using Bayes' Rule, and off the equilibrium too for all histories in class (i) they satisfy the requirement; finally for histories that occur with zero probability given $\hat{s}$, since all beliefs, $b \in B$ are admissable, the specified beliefs too meet the requirement. This completes the existence proof. Next it is shown that $(\hat{s}, \hat{b})$ satisfies the requirements of stage-game and signalling norms.

Stage-game norms: $\hat{s}$, implies that both players play l in the first stage-game. This proves that in this equilibrium players start by conforming to stage-game norms.

Signalling Norms: Signalling norms pertain to actions, for all histories where players have not already switched, and updating of beliefs $\forall h_i^{t'}$, s.t., $\forall t < (t'-1), h_{i,t} = (l,1)$, and $h_{i,t'-1} = (l,0)$, for the type U player. $\hat{s}_i$ satisfies the requirement, since for all histories of this type that can occur, i.e., classes (i) and (ii), it recommends actions that fulfill the signalling norm beliefs of the players. Next consider the beliefs, $\hat{b}$; given $\hat{s}_{-i}$, irrespective of whether $T_{-i,t'} = I$ *or* U, $\forall h_i^{t'}$, s.t., $\forall t < (t'-1), h_{i,t} = (l,1)$, and $h_{i,t'-1} = (l,0)$, Bayes' updating by type U player implies that $\{\mu_{i,t'}^2 + \mu_{i,t'}^3 = 1\}$. Off the equilibrium path too this requirement is satisfied, by construction. **Q.E.D.**

Proof of Proposition 3: Fix the number of actions in the game, N, and consider a signalling equilibrium, in which players start by conforming to stage-game norms. Also fix the evolution to be s.t.,$\forall t \geq \hat{t}$, $G_{t,k} = G_{3,\hat{j}}$, for some $\hat{j} \in [\frac{N-1}{2}, N-1]$. Note that the probability of such realizations, for $\hat{j} \in [\frac{N-1}{2}, N-1]$ will be at least $\frac{1}{2}$, always, in our structure. For such an equilibrium to be efficient it is required that type I switch and so we focus on the decision of type I player, after nature has moved and the new stage game is $G_{3,\hat{j}}$ for some $\hat{j} \in [\frac{N-1}{2}, N-1]$.

Player of type I will switch only if, following on the argument of Theorem 1, $X_{sn}^{\infty}(I) \geq X_{ns}^{\infty}(I)$ or, if $X_n^{\infty} \geq X_{ns}^{\infty}(I)$.

In the randomized search case, the optimal way to search, for the type U player, is to randomly move between the actions, eliminating one at a time. Given this search process, the pay-offs for the type I player may be computed as follows:

$X_{sn}^{\infty}(I) = 0.\alpha_1 + \frac{1}{N-1}\frac{\delta.\alpha_1}{1-\delta} + ... + \frac{1}{N-1}\frac{\delta^{N-1}.\alpha_1}{1-\delta}$

$= \frac{\alpha_1}{1-\delta}\frac{\sum_{t=1}^{N-1}\delta^t}{N-1}$

On the other hand,

$X_{ns}^{\infty}(I) = \frac{1}{1-\delta}.$

Thus for type I to switch from l to $r_{\hat{j}}$, it is necessary that, $\alpha_1 \frac{\sum_{t=1}^{N-1}\delta^t}{N-1} \geq 1$, and this implies that $\alpha_1 \geq \frac{N-1}{\sum_{t=1}^{N-1}\delta^t}$. Following on the argument in Theorem 1, a similar expression is valid for switching n periods from now. As N increases the expression on the r.h.s. is unbounded. That completes the argument in the case of randomized search by the type U player.

In the case of deterministic search by type U player, the optimal response of the type I player is to coordinate with the type U player, in the stage-game actions, in the interim search period. The pay-offs from switching now, $X_{sn}^{\infty}(I)$ are then calculated as follows:

$X_{sn}^{\infty}(I) = 0 + \delta.\beta + \delta^2.\beta + ... + \delta^{\hat{j}}.\frac{\alpha_1}{1-\delta}$

Given that $X_{ns}^{\infty}(I) = \frac{1}{1-\delta}$, the type I player will signal $r_{\hat{j}}$, only if $\alpha_1 \geq \beta + \frac{1-\delta.\beta}{\delta^{\hat{j}}}$. A similar argument can be made for the option of switching n periods from now, as in Theorem 1. But as the number of actions N gets large, and hence $\hat{j}$ gets large, the r.h.s of the above expression is unbounded. This completes the proof. **Q.E.D.**

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