

**Strategy Meets Evolution:
Games Suppliers and Producers Play**

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**STRATEGY MEETS EVOLUTION :
GAMES SUPPLIERS AND PRODUCERS PLAY**

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Abstract

Final goods producers, who may be *intrinsically* honest (a behavioral type) or opportunistic (strategic), play a repeated game of imperfect information with suppliers of an input of variable (and non-verifiable) quality. Returns to cheating are increasing in the proportion of intrinsically honest producers. If producers compete for another scarce input, adverse selection reduces this proportion enough to enforce universal honesty, whether at a high or a low quality equilibrium. This mechanism limits the proportion of *behavioral* types in the population of producers over a wide range of parameters: despite their inability to compete with opportunists, they are not wholly wiped out due to the *strategic* response of input suppliers. Moreover, in equilibrium, opportunists must replicate the behavioral type's behavior. Thus competition curtails the presence of the behavioral type but increases the incidence of its behavior. If a labor market, where skilled and unskilled labor coexist, is also endogenized, an honest equilibrium with both high and low quality will generally be reached; however an exclusively high quality equilibrium with unemployment of unskilled labor is also possible.

JEL Classification : C7, D8, J4.

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1. Introduction

Recent theory has been divided on the merits of continuing to assume that all economic agents are perfectly rational, where rationality is defined as following fully optimizing behavior. Accordingly, there has been no dearth of studies modeling some form of bounded rationality. In particular, two main alternatives to “strategic” or “fully optimizing” behavior were developed – evolutionary game theory and adaptive heuristics. In the former, agents follow a fixed “outcome-independent” strategy : different proportions of agents in the population follow different strategies and evolution “selects” the best strategy – or set of strategies - over time, subject to “mutations” – random changes or transitions in the strategy followed. In the latter, agents are not perfectly rational but may use a simple rule (for example, one based on regret matching – see Hart (2005)) to determine whether to switch to an alternative strategy.

Our paper attempts to fill a gap in this literature by focusing on the *interaction* between strategic optimizing types and types following a behavioral rule, when both types belong to a class of agents playing a repeated game against agents of another class (who, for simplicity, are all assumed to be rational). We apply our analysis to a problem of moral hazard between input suppliers, who supply inputs of variable but non-verifiable quality to final goods producers. Transfer prices for the inputs may be determined through Nash bargaining, however, final producers have the option to cheat their suppliers by falsely claiming that the input they had been supplied was of low quality, thus paying a low price for a high-quality input. The population of final producers is heterogeneous, with some intrinsically honest agents who always stick to honesty irrespective of economic considerations, and some opportunistic producers who are standard optimizing agents. Matching is the result of a search process, but once a match is formed it can persist into future periods unless it is terminated either exogenously or deliberately. We describe possible equilibria in three different models. All the models have the common feature that suppliers can supply inputs of high quality (using skilled labor at a wage w_s) or low quality (using unskilled labor at a wage w_u) to heterogeneous producers (either intrinsically honest or opportunistic) who transform these inputs into high or low quality products respectively which sell at prices P_H and P_L .

In our first model, we have exogenous wages and final prices, implying perfectly elastic supply of all primary factors and perfectly elastic demand for all final products, as in a small open economy (so that there is no competition between producers in the factor or product markets).

In the second, wages and final prices are still exogenous, but production requires an additional factor, working capital, which is in inelastic supply and for which producers have to compete. The element of *competition* introduces the interaction between strategic and behavioral agents, both of whom are playing against agents of another class. Interestingly this mechanism serves to limit the proportion of behavioral types in the population for a wide range of parameters. The behavioral types' strategy is inferior, in the relevant parameter space, and this leads to their downfall : however, the type is not entirely wiped out, and this is due to the strategic response of *input suppliers* – the other class of agents. What is more, in contrast to the first model, equilibria in this model necessarily involve honesty – whether high or low quality is being supplied. Thus, although the proportion of the behavioral *type* in the population goes down, their *strategy* is now followed by every one. We therefore have a situation where, although “survival of the fittest” operates, the strategies followed by the unfit may prevail in equilibrium, due to the strategic interaction with other agents (input suppliers). Incorporation of the channel of competition between producers changes behavior in equilibrium, and also rules out *multiple equilibria* obtaining for the same parameter ranges that characterized the first model – serving as an *equilibrium selection device* for the relevant range of parameters.

In our third model, wages are endogenously determined by labor demand and inelastic supplies of each labor skill, though final product prices remain exogenous (as they would be in a small open economy). In general, we can show that a single equilibrium obtains here where both high and low quality co-exist – with workers of both skill levels being employed – but in some circumstances (if exogenous separations of matches are very frequent, and agents are impatient) we may have an equilibrium in which there is involuntary unemployment of unskilled labor, with only high quality being supplied and produced in equilibrium.

Our paper thus relates to two of the three approaches in modeling agent behavior mentioned above – fully optimizing behavior and a behavioral genotype. We do not deal with adaptive heuristics. One strand of the related literature encompasses models of repeated moral hazard between fully optimizing players. This is an extensive literature and the ideas underlying it date at least as far back as Williamson (1979) and Grossman and Hart (1986). One or two-sided prisoner’s dilemma models with scope for cheating include those by Diamond (1991), Dixit (2003) and Greif (1993). Often, prisoner’s dilemmas in large populations exhibit i.i.d random matching in such papers, in contrast to our approach of allowing for persistent relationships, though a relationship may be terminated either deliberately or due to exogenous reasons. Papers such as Gul (2001) analyze hold-up problems and bargaining in a buyer-seller context, and this is also related to our model.

Some papers (eg Dixit 2003) also contain some behavioral players in a two-sided prisoner’s dilemma. However, there is no mechanism whereby the optimizing and the behavioral players belonging to the same class of agents *compete* : as such the second model in our paper, by introducing such a mechanism, lends itself to an *evolutionary* interpretation – the force behind *selection* being an economic one. This brings us to another relevant strand of literature, that on evolutionary game theory. Unlike standard evolutionary models we emphasize the effect of strategic or optimizing agents on behavioral types and on strategies that survive in a population. Moreover, the mechanisms embedded in our second model as well as in our third model (which enables us to characterize conditions in the labor market in a general equilibrium setting and to predict in what circumstances involuntary unemployment of unskilled labor may emerge) serve as equilibrium selection devices eliminating the possibility of multiple equilibria for the same parameter values. So this links our work to the literature on equilibrium selection (which includes Myerson (2004)).

2. Model I : Perfectly Elastic Factor Supplies

2.1 Assumptions

We assume that suppliers can supply inputs of high quality (using skilled labor at a wage w_s) or low quality (using unskilled labor at a wage w_u) to heterogeneous

producers (either intrinsically honest or opportunistic) who transform these inputs into high or low quality products respectively which sell at prices P_H and P_L .

For the purposes of this first model, wages of both types of labor are exogenously fixed, all inputs are in perfectly elastic supply and hence there is no competition between producers in the factor market. Throughout we assume that final good prices are exogenous as in a small open economy. Moreover parameters are such that $P_H - w_s > P_L - w_u$ so that the total surplus (to be shared among each matched supplier and producer) from high quality production is never lower than that associated with low quality production.

There are M suppliers and N producers where M and N are large numbers and $M < N$. Of the N producers, a proportion α is intrinsically honest.

Each period one supplier can be matched with only one producer, and vice versa. Matching involves *search* by suppliers and producers who are on the market for new matches : however those whose previous match has not been either deliberately or exogenously terminated remain in the old relationship and do not enter the market. A fraction $1-\gamma$ of all matches terminate exogenously (so that $1-\gamma$ is the probability of exogenous separation).

Our assumption regarding informational structure throughout is that instances of cheating are not public knowledge and are observed only by the cheated party.

Once a match occurs, the matched supplier and producer decide on a contract. The non-verifiability of product quality makes any such contract incomplete. However, contracts can be so designed as to make it feasible – though not necessarily profitable – for either the producer or the supplier to cheat. If the producer has the option to decide on the price he will pay after inspecting the input, he is insured against being cheated, but has the opportunity himself of cheating by paying a low price for high quality. If he surrenders this option and agrees to pay a fixed pre-negotiated price, he cannot cheat and is vulnerable instead to cheating by the supplier, who could offer him low quality where the contract specifies high. Nor can the producer protect himself against cheating by threatening either to terminate the supply relationship or to pay a low price ever after. Such threats have no punitive value: the dismissed supplier can enter the market masquerading as someone exogenously separated and secure a new match with

probability one. Indeed, the supplier can himself dissolve the relationship to counter the low-price threat immediately after collecting the pre-negotiated price and move on to another “one-night stand”. Since the producer anticipates this, such contracts, even if feasible, will never actually be concluded. We can focus therefore exclusively on contracts where the producer has the right to decide whether to pay a high or a low price after receiving the supply.

Apart from this angle, the contract must specify the transfer prices the supplier is to be paid for high and low quality inputs. These are denoted by p_H and p_L respectively. We assume Nash bargaining. If the transfer prices are contingent on the quality that the producer claims to have received, they are not strictly implementable by law; however, though input quality is non-verifiable, the transfer prices themselves as well as the fact of input delivery are all legally verifiable, therefore suppliers have to be paid a minimum of p_L . If a producer cheats by making a false claim about input quality and accordingly paying a low price, the supplier can retaliate by supplying the opportunistic producer low quality ever after or even by deliberately terminating the relationship. In the latter event, the producer has to search for a new partner. He is not necessarily branded as a cheat by the mere fact of a severed relationship since there is a given probability $1-\gamma$ of an exogenous separation. However, he faces an uncertain prospect q (which we endogenize) of finding a new match in the next period.

The low quality price is determined with reference to the threat point of no transaction (which yields a surplus of zero to each party). The Nash product $(P_L - p_L)(p_L - w_u)$ is maximized at $p_L = (P_L + w_u)/2$. If the producer claims to have received low quality, this is the price he must pay.

The contract can be sustained by two threats, termination and low-quality supply. However, we need not consider the threat of low-quality supply and its impact on producer behavior. If this is not as severe a threat as termination, a producer who can withstand the termination threat will automatically be able to withstand the low-quality threat as well. If, on the other hand, low-quality supply reduces the producer’s income more than termination does, the producer, after cheating the supplier, can always dissolve

the partnership himself, thus rendering the low-quality threat irrelevant². We shall determine the parameter range over which termination is an effective threat.

Curiously however, in the parameter range where the contract is not implementable, it may yet be concluded between supplier and producer in full knowledge that it will not be generally implemented. We then have a cheating equilibrium: suppliers provide high quality, are cheated by all opportunistic producers, whom they replace by a newcomer in every period; however, the proportion of honest producers who pay the suppliers p_H is high enough for the latter to persist with the provision of high quality.

2.2 Timing

In the beginning of each period, suppliers and producers who are on the market for new matches search for a match, and if successful, enter into a relationship. Those not on the market continue with their previous relationships.

Prior to production of the input, each matched agent bargains with his match, determining the transfer prices to be paid for high or low-quality inputs. Then matched suppliers supply either high or low quality (and hire skilled or unskilled labor accordingly).

Each matched producer then takes possession of the input and decides what to pay on the basis of quality. If a low quality input has been supplied, both honest and opportunistic producers pay p_L . If the input was of high quality, opportunistic producers decide whether to deal honestly, paying p_H , or to cheat, paying p_L : intrinsically honest producers pay p_H .

Depending on the actual quality of the input supplied, matched producers then produce a good of high or low quality. At the end of the period, suppliers may choose to break off the relationship, in which case they and their separated partner both enter the market for new matches in the next period. Or the match may terminate exogenously, in which case the same outcome ensues. If neither occurs, both parties continue with the relationship. The whole process is then repeated ad infinitum.

² The payoff of a producer who has voluntarily terminated his partnership with a supplier is identical with that of one who has been punished by termination.

2.3 Strategies and Equilibria

Quality-contingent Nash bargaining prices are determined assuming that in each match, a supplier and a producer equally divide the surplus $(P_H - w_s)$ for high quality and $(P_L - w_u)$ for low. Then the transfer prices are given by $p_H = \frac{P_H + w_s}{2}$ and $p_L = \frac{P_L + w_u}{2}$.

We note that $p_H > p_L$ given the assumption that $P_H - w_s > P_L - w_u$.

In the one-stage game opportunistic producers have a clear incentive to cheat suppliers who supply them with a high quality input, paying them only p_L – thus appropriating cheating gains of $p_H - p_L$. If all producers were opportunistic, the suppliers' best response would be to always supply low quality as this would give them a payoff of $p_L - w_u > p_L - w_s$ which they get from supplying high quality to producers who then cheat them. However, some producers (a fraction α) are honest in our framework and will pay p_H if high quality is supplied. Hence, suppliers decide on what quality input to supply based on their expectation over types in the population (they cannot ex-ante distinguish opportunistic firms from honest ones) : they supply low quality iff

$$\alpha(p_H - w_s) + (1 - \alpha)(p_L - w_s) < p_L - w_u$$

or iff

$$\alpha < \frac{w_s - w_u}{p_H - p_L} = \frac{2(w_s - w_u)}{P_H - P_L + (w_s - w_u)}$$

given the Nash-bargaining determined values of the transfer prices. In this event they are always paid p_L and opportunistic producers do not get a chance to cheat. Otherwise, they supply high quality, are cheated by opportunistic producers and are paid p_H by honest producers.

In the repeated game we allow for exogenous terminations and endogenize search probabilities. Note that uncertain search and exogenous terminations imply that merely observing that a producer's previous matches had been terminated does not enable other potential suppliers to identify him as a cheat.

Given our contract, only producers can cheat and the suppliers' deterrent strategies involve punishing a producer who cheats either by deliberately terminating the relationship or by supplying low quality thereafter as long as the relationship lasts. We

examine the parameter ranges in which either of these threats enforces a high-quality honest equilibrium. We then go on to describe two other kinds of equilibria that could exist, depending on the parameter values. For some parameters multiple equilibria may exist.

(1) A high-quality honest equilibrium : Every period, matches occur between suppliers and producers who are both on the market. Let q_H be the probability of a producer on the market finding a match in an honest equilibrium. Once a match is formed it persists unless it terminates exogenously. There is no cheating and therefore no punitive separations. The number of earlier matches persisting into any given period is equal to :

$$M - (1 - \gamma)M = \gamma M \quad (1)$$

As suppliers constitute the short side of the market, all M suppliers can find matches but of these matches a fraction $1 - \gamma$ terminate in each period, as indicated above. Therefore the number of producers on the market equals the total number of producers N , less the ones in matches that persist from earlier periods : or

$$N - \gamma M \quad (2)$$

while by a similar argument the number of suppliers on the market is

$$M - \gamma M \quad (3)$$

From (2) and (3), the probability of a producer on the market finding a match is:

$$q_H = \frac{(1 - \gamma)M}{N - \gamma M} \quad (4)$$

This endogenizes q in an honest equilibrium. q_H is evidently decreasing in γ . Equivalently, it is increasing in the probability of exogenous separation.

What conditions support an honest equilibrium? Recall that the effective off-equilibrium threat is for a cheated supplier to terminate his relationship with the cheat. This threat is costless for the supplier, as next period he is sure to find another match, from whom he can expect a strictly higher payoff than from the cheat (even if other opportunists also wanted to cheat, there is some probability that the new match will be an intrinsically honest type). When will this threat be effective in deterring deviations by producers? Let V_H be the lifetime expected payoff of a matched producer in an honest high-quality equilibrium, and let V_{HU} be the payoff of an unmatched producer in this equilibrium. Then

$$V_H = (P_H - p_H) + \delta\{\gamma V_H + (1 - \gamma)V_{HU}\} \quad (5)$$

The first bracketed term denotes the producer's payoff from acting honestly in his current match, while the term in braces shows that if the match terminates exogenously (with probability $(1 - \gamma)$) the producer gets the payoff of an unmatched producer, otherwise he continues to get the payoff of a matched producer : his future expectation is discounted by the discount factor δ . Now a producer whose match terminates exogenously finds a new match with probability q_H , where q_H is given by (4) : otherwise, his "unemployment" persists into the next period. Thus, we have

$$V_{HU} = q_H V_H + (1 - q_H)\delta V_{HU}$$

Or

$$V_{HU} = \frac{q_H}{1 - \delta(1 - q_H)} V_H \quad (6)$$

Substituting (6) in (5) and simplifying,

$$V_H = (P_H - p_H) \frac{1 - \delta(1 - q_H)}{(1 - \delta)(1 - \delta\gamma(1 - q_H))} \quad (7)$$

Let V_D be the payoff to a deviant producer in this equilibrium. A deviant cheats and gets $P_H - p_L$, but then the cheated supplier terminates the relationship. After this, the deviant would have to search for a new match. So

$$\begin{aligned} V_D &= P_H - p_L + \delta q_H \text{Max}(V_D, V_H)[1 + \delta(1 - q_H) + \delta^2(1 - q_H)^2 + \dots] \\ &= P_H - p_L + \frac{\delta q_H}{1 - \delta(1 - q_H)} \text{Max}(V_D, V_H) \end{aligned} \quad (8)$$

The condition to rule out deviations is that

$$V_D < V_H$$

In this case,

$$V_D = P_H - p_L + \frac{\delta q_H}{1 - \delta(1 - q_H)} V_H < V_H$$

Or

$$V_H > [P_H - p_L] \frac{1 - \delta(1 - q_H)}{1 - \delta} \quad (9)$$

Equivalently, from (7) and (9),

$$P_H - p_H > [P_H - p_L] \{1 - \delta\gamma(1 - q_H)\} \quad (10)$$

We have already argued that the threat of perpetual low-quality supply has no independent force since the producer can circumvent it by dissolving the relationship himself.

An honest equilibrium is thus ensured in the parameter range (10).

Now we focus on the termination threat and turn to the description of other possible equilibria³. This leads us to :

(2) A “high quality cheating equilibrium”: This is an equilibrium where suppliers always supply high quality but are paid the low price p_L by all opportunistic types in spite of the termination threat⁴. What are the conditions required to support such an equilibrium?

We first examine the conditions that make it optimal for opportunistic producers to always cheat when supplied with high quality (if they are supplied low quality, then of course they have no opportunity to cheat). Suppose we are in an equilibrium where high quality is being supplied and opportunistic producers are always cheating. Then in each match, they make $P_H - p_L$ – each instance of cheating is followed by immediate termination of the relationship, followed by renewed cheating if and when a new match is found. The number of matches from earlier periods persisting into the current period is :

$$M - (1-\gamma)M - \gamma(1-\alpha)M = \alpha\gamma M \quad (11)$$

The third term being subtracted denotes the matches that were deliberately terminated because the suppliers in question were cheated by opportunistic producers. Therefore, the number of suppliers on the market is

$$M(1-\alpha\gamma) \quad (12)$$

While the number of producers on the market is N minus the number in matches persisting from earlier periods, or

³ Reversion to supplying low quality forever in a repeated relationship is essentially the trigger strategy of resorting to the one-shot Nash equilibrium in a two player game. We wish to focus on the richness added to the model as a result of allowing for multiple suppliers and producers and uncertain search. As we shall show shortly, supplying low quality is the equilibrium strategy for some parameter ranges even when a termination threat constitutes the off-equilibrium punishment for cheating – however, for other parameter values, high quality may be supplied.

⁴ Of course, intrinsically honest producers never cheat their suppliers.

$$N - \alpha\gamma M \quad (13)$$

So the probability of a producer on the market finding a match in this cheating equilibrium is

$$q_c = \frac{M(1 - \alpha\gamma)}{N - \alpha\gamma M} \quad (14)$$

We note that $q_c > q_H$. Because of the greater number of terminations in a cheating equilibrium, there are more suppliers on the market and this makes it easier for a producer whose relationship has terminated to find a new match.

Denoting the opportunist's payoff to following a cheating strategy by V_c ,

$$\begin{aligned} V_c &= [P_H - p_L][1 + \delta q_c + \delta^2 q_c + \dots] \\ &= [P_H - p_L][1 + \frac{\delta q_c}{1 - \delta}] \\ &= [P_H - p_L][\frac{1 - \delta(1 - q_c)}{1 - \delta}] \end{aligned} \quad (15)$$

For opportunistic producers to have no incentive to deviate from this strategy, we require V_c to exceed V_{Dc} , which denotes the payoff of a deviant in a cheating equilibrium. A one-time deviation consists of paying p_H for high quality, so that barring exogenous terminations, the relationship persists. Thus we require:

$$V_{Dc} = P_H - p_H + \delta\gamma V_c + \delta(1 - \gamma)q_c V_c [1 + (1 - q_c)\delta + (1 - q_c)^2\delta^2 + \dots] < V_c$$

Or

$$V_{Dc} = P_H - p_H + \delta\gamma V_c + q_c V_c \frac{\delta(1 - \gamma)}{1 - \delta(1 - q_c)} < V_c$$

Simplifying, this gives us:

$$[P_H - p_H] \frac{1 - \delta(1 - q_c)}{(1 - \delta)(1 - \delta\gamma(1 - q_c))} < V_c$$

or from (15),

$$P_H - p_H < [P_H - p_L] \{1 - \delta\gamma(1 - q_c)\} \quad (16)$$

(16) is the condition supporting a high quality cheating equilibrium on the producers' side.

When will suppliers support this equilibrium by supplying high quality in spite of the knowledge that all opportunistic producers might cheat? The suppliers' choice of

move depends on their expectation over intrinsically honest and opportunistic types : if α , the proportion of intrinsically honest types, is above a threshold α^* they may choose to supply high quality, correctly anticipating that the probability of encountering a cheat is low. We prove in the appendix that this threshold is given by

$$\alpha^* = \frac{w_s - w_u}{\frac{1-\gamma}{1-\delta\gamma}(p_H - w_s) - (p_L - w_s) + \frac{(p_L - w_u)}{1-\delta} \left\{ \gamma - \delta + \frac{\delta(1-\gamma)^2}{1-\delta} \right\}} \quad (17)$$

Thus, when opportunists have no incentive to deviate from cheating if supplied with high quality, the supplier supplies high quality if and only if the fraction of intrinsically honest producers is high enough, i.e when:

$$\alpha > \alpha^* \quad (18)$$

Both (16) and (18) must hold for a “high quality cheating equilibrium” to be supported. A third alternative is :

(3) The low quality equilibrium : If (18) does not hold, but (16) does, suppliers have a higher expected payoff from supplying low quality than from high quality – knowing that if they supplied high quality, all opportunistic producers would have an incentive to cheat them. Thus in this case all suppliers supply low quality and opportunistic producers have no opportunity to cheat. The conditions supporting this equilibrium are (16) and

$$\alpha < \alpha^* \quad (19)$$

Obviously, the same parameter values cannot support both a low quality equilibrium and a high quality cheating equilibrium, as conditions (18) and (19) are obverses of each other. Comparing conditions (16) and (10), and noting that $q_c > q_H$, we see that if (16) does not hold, then (10) automatically does. In other words, if a cheating equilibrium is impossible to sustain, an honest equilibrium is always possible. This is not surprising when we consider that the penalty for a deviation in an honest equilibrium is a period of uncertain search after being fired by the cheated supplier and that the probability of being successful in this search is even lower in an honest equilibrium than in a cheating equilibrium. If, on the other hand, (10) does not hold, so that an honest equilibrium is not sustainable using the termination threat, (16)

automatically holds and a cheating equilibrium can exist provided α is high enough to induce suppliers to supply high quality. If the danger of uncertain search is insufficient to deter deviations from an honest equilibrium, the probability of a cheat's being able to find a match is certainly high enough to support cheating behavior when all other opportunists are cheating and there are many more suppliers on the market.

There is also a range where it is possible for both (10) and (16) to hold. This is a range of parameter values for which multiple equilibria are possible. If opportunists thought that all other opportunists would be honest, no single one of them would have an incentive for a profitable deviation – yet cheating might be profitable if all other opportunists were cheating too. In this range co-ordination would determine which particular equilibrium would obtain. If $\alpha < \alpha^*$, suppliers might decide to supply low quality from the outset, if they thought opportunistic producers were likely to co-ordinate on a cheating equilibrium in the event of being supplied with high quality. If $\alpha > \alpha^*$, however, high quality would be supplied and then either an honest or a cheating equilibrium is possible.

We can summarize equilibrium strategies in our first model thus:

1. The suppliers' first move : If (16) does not hold – and by implication (10) does – then suppliers supply high quality. If (16) holds, then suppliers supply high quality if $\alpha > \alpha^*$ and low quality otherwise.
2. The producers' first move : If (16) does not hold – and (10) does – then all producers pay the suppliers p_H for the high quality input. If (16) holds, and (10) does not, opportunistic producers pay suppliers p_L whether supplied with high or low quality : intrinsically honest producers pay p_H for high and p_L for low quality. If both (16) and (10) hold, and suppliers provide low quality, all producers pay p_L , while if suppliers provide high quality, either of two equilibria could result : in one, all producers pay p_H : in the other, only intrinsically honest producers do so while all opportunists pay p_L .
3. The suppliers' second move : If paid p_H for high quality or p_L for low quality, suppliers continue their relationship with their match : otherwise, if paid p_L for high quality, they terminate it. They then repeat their first move – if necessary, with new producers.

4. The producers' second move : Producers continue in their old relationship unless it terminates and search for a new match if it does. They then repeat their first move with old partners or any new matches : and if unmatched, they continue their search.

In terms of the parameters $P_H - p_H$, $P_H - p_L$, we have the following possibilities:

1. $P_H - p_H > (P_H - p_L)[1 - \delta\gamma(1 - q_c)] > (P_H - p_L)[1 - \delta\gamma(1 - q_H)]$: the region of high-quality honest equilibrium.
2. $P_H - p_H < (P_H - p_L)[1 - \delta\gamma(1 - q_H)] < (P_H - p_L)[1 - \delta\gamma(1 - q_c)]$ and $\alpha < \alpha^*$: the region of low-quality honest equilibrium.
3. $P_H - p_H < (P_H - p_L)[1 - \delta\gamma(1 - q_H)] < (P_H - p_L)[1 - \delta\gamma(1 - q_c)]$ and $\alpha > \alpha^*$: the region of cheating equilibrium.
4. $(P_H - p_L)[1 - \delta\gamma(1 - q_c)] > P_H - p_H > (P_H - p_L)[1 - \delta\gamma(1 - q_H)]$: the region of multiple equilibria.

An implication of this analysis is that opportunities for cheating are an increasing – albeit discontinuously increasing – function of the level of honesty of the population of producers. Cheating can prevail only if α exceeds a threshold : with fewer honest producers, suppliers will be disinclined to supply high quality, so that the larger number of opportunists will be denied any scope for cheating.

3. Model 2 : Competition, Adverse Selection and Effects on Evolution

3.1 The Mechanism

In this model, wages and product prices are still exogenous. However, there is one factor, capital, which is in *inelastic* supply : there is competition for this in the factor markets. Each unit of output has a fixed capital requirement of one unit in addition to its intermediate input requirement. Let r stand for the opportunity cost of this capital. This alters the Nash-bargaining determined expressions for the transfer prices to $p_H = \frac{1}{2}[P_H - r + w_s]$ and $p_L = \frac{1}{2}[P_L - r + w_u]$. The analysis parallels that in the first model and we have parallels to conditions (10) and (16) :

$$P_H - r - p_H > [P_H - r - p_L]\{1 - \delta\gamma(1 - q_H)\} \quad (10')$$

and

$$P_H - r - p_H < [P_H - r - p_L]\{1 - \delta\gamma(1 - q_c)\} \quad (16')$$

Conditions (18) and (19) remain as before as does the threshold α^* .

Let us consider a situation where $P_H - r - p_H < (P_H - r - p_L)[1 - \delta\gamma(1 - q_H)] < (P_H - r - p_L)[1 - \delta\gamma(1 - q_c)]$ and $\alpha > \alpha^*$. Comparing this to the account of the equilibrium strategies in model 1, we see that by cheating, opportunistic producers would earn profits of $[P_H - r - p_L] \frac{1 - \delta(1 - q_c)}{1 - \delta}$ while intrinsically honest producers would earn

$$[P_H - r - p_H] \frac{1 - \delta(1 - q_c)}{(1 - \delta)(1 - \delta\gamma(1 - q_c))}^5. \quad \text{We can instantly see from the fact that condition}$$

(16') holds that opportunistic firms are making strictly higher profits as long as they continue to pay investors the same r that honest firms are paying. Let us assume that honest firms are paying the maximum rate of return, r_H , needed to equate their profits to their opportunity cost. Then, if we assume that honest and opportunistic firms have the same opportunity costs (perhaps because there are no profitable opportunities for cheating outside the industry), opportunistic firms can offer a return up to $r_O > r_H$ where

$$P_H - r_H - p_H = [P_H - r_O - p_L]\{1 - \delta\gamma(1 - q_c)\} \quad (20)$$

The supply of funds being inelastic, firms offering a higher r succeed in attracting all the capital. This is not only feasible, but also profitable for the firm, since its stock of capital is the only constraint on its output and profits. Thus, opportunistic firms can drive the less profitable honest firms out of business. But then no equilibrium is possible with $\alpha > \alpha^*$ - as long as the proportion of intrinsically honest firms is higher than this, honest firms will continue to be driven out of business by competition with opportunists who are able to earn higher profits as a consequence of cheating. Therefore, in equilibrium α cannot exceed α^* and will be driven down to this proportion if it was initially higher. If, however, $\alpha \leq \alpha^*$ to start with, suppliers would offer low quality, opportunists would have no opportunities for cheating; they would be forced willy-nilly to behave like honest firms and would not therefore be able to lure away capital from the latter by offering higher returns.

⁵ This is like the V_H producers earn in an honest equilibrium, except that the relevant q is now higher - q_c , not q_H , as we are in a cheating equilibrium.

On the other hand, if $(P_H - r - p_L)[1 - \delta\gamma(1 - q_H)] < P_H - r - p_H < (P_H - r - p_L)[1 - \delta\gamma(1 - q_C)]$, we are in the region corresponding to the “multiple equilibria” region of Model 1 : suppliers would supply high quality, and opportunists would cheat or act honest according to whether they expect other opportunists to cheat or act honest. If they all act honest, all producers would make the same profits, so there would be no destructive competition of the kind outlined above. If, however, they coordinate on a cheating equilibrium, the opportunists would make a higher rate of profit than honest producers if they pay the same r on their capital as the latter. They would then have the incentive and the ability to raise their r above the maximum that the honest firm could pay. Suppliers, knowing this, realize that the fraction of intrinsically honest producers would be driven down to α^* and so would only supply low quality, and producers would accordingly be unable to cheat. This may in fact wipe out the multiplicity of equilibria as suppliers, knowing that producers have an incentive to cheat, and also knowing that α cannot exceed α^* in equilibrium, supply low quality as long as $P_H - r - p_H < (P_H - r - p_L)[1 - \delta\gamma(1 - q_C)]$. This perforce results in a low quality equilibrium without cheating. The motivation to supply high quality when cheating is possible is eliminated as the proportion of intrinsically honest producers in equilibrium is no longer high enough. This underscores the potential of the element of competition between producers for capital to serve as a co-ordination device in the region of multiple equilibria.

Finally, if $P_H - r - p_H > (P_H - r - p_L)[1 - \delta\gamma(1 - q_C)] > (P_H - r - p_L)[1 - \delta\gamma(1 - q_H)]$, a high quality honest equilibrium is assured.

Thus in our second model, only two possible equilibria remain. If $P_H - r - p_H > (P_H - r - p_L)[1 - \delta\gamma(1 - q_C)] > (P_H - r - p_L)[1 - \delta\gamma(1 - q_H)]$, there is a high quality honest equilibrium.⁶ Otherwise, a low quality equilibrium obtains, because even if the proportion of intrinsically honest types started out high enough to induce suppliers to supply high quality regardless of (16') holding, competition would drive out enough honest types to induce suppliers to supply low quality instead. Thus the market mechanism of competition for capital drives out honest types and thereby eliminates actual cheating behavior. As long as (16') holds, opportunistic producers continue to

⁶ Note that the equilibrium probabilities of successful search may differ slightly from Model 1 because some intrinsically honest producers leave the market in some parameter ranges. This does not make a qualitative difference : the probabilities in Model 2 are derived in the appendix.

have an incentive to cheat; unfortunately for them, they get no *opportunity* to do so. Adverse selection actually enforces an honest equilibrium.

3.2 Discussion

While this model thus compels honesty in equilibrium, in a wide range of parameters (those where (16') holds) it also sets an upper limit to the proportion of *intrinsically* honest producers who can survive in the market. This limit is determined endogenously by market parameters unrelated to the level of natural honesty of the population of producers. In equilibrium, cheating is never observed, yet honesty is not necessarily the best policy out of equilibrium.

Another counterintuitive aspect of this model is that expectations here have a self-defeating, rather than a self-fulfilling, quality. If suppliers expect to encounter more dishonesty among producers, this may well rule out dishonest behavior altogether. The reason is that it induces suppliers to take defensive precautions so strong that producers cannot cheat, much though they may want to.

While our first model was of a repeated game being played between two classes of agents, where one class was heterogeneous in comprising of both “strategic” players (opportunistic producers) as well as “behavioral players” (intrinsically honest ones), our second model has gone beyond this to introduce a channel of competition *within* the same class of agents, so that players following behavioral rules have to interact with those following optimizing strategies, while both at the same time are playing a game against another class of strategic agents – input suppliers. A purely economic channel serves to drive out some behavioral players in parameter ranges where their behavioral rule is an “unfit” or unprofitable strategy. This may be regarded as a type of *selection* determining long run survival. There are a couple of twists to this evolutionary story⁷. The strategic response of the other class of agents – input suppliers – *limits* the extent to which the selection process can go : once there are few enough behavioral types in the population of producers, suppliers change their behavior by supplying only low quality inputs so that

⁷ The rest of this paragraph refers to the case where (16') holds so that selection through competition is not a moot issue.

all producers now make the same profits and weeding out of behavioral types stops. Secondly, while unfit *players* (or some of them) are weeded out during selection : the *strategy* followed by these unfit players grows in importance in the sense that *every one* is now honest in equilibrium. This result contrasts with the traditional wisdom in evolutionary games where the survival of a *strategy* followed by a type in the population is more or less equated to the survival of the *type*. Our result differs due to the strategic responses of input suppliers who change their behavior so as to eliminate opportunities for cheating. In other words, their response alters the environment so that the strategy followed by the “unfit” players becomes the only feasible one.

4. Model 3 : Endogenous Wages

In this model, we use a general equilibrium framework to endogenize wages of skilled and unskilled labor (assumed to be elastically supplied at given wages in the first two models). Here, labor types of different skills are in inelastic supply and their wages are solely determined by demand. However, product prices P_H and P_L still remain exogenous, as in a small open economy.

Model 2 shows that competition for capital reduces the proportion of honest producers to a level where no opportunities for cheating remain. We either have a high-quality honest equilibrium or a low quality equilibrium.

However, if both skilled and unskilled labor exist in the economy, neither of these two options will be compatible with a full-employment labor market equilibrium. Excess supply of one kind of labor or another can be avoided only if both high and low quality coexist. Labor market equilibrium requires that

1. suppliers should be indifferent between supplying high and low quality;
2. the quality composition of supply should correspond to the skill composition of labor;
3. producers who receive high quality supply should pay the high price and those who receive low quality supply should pay the low price.

Conditions 1 and 3 imply that

$$p_H - w_s = p_L - w_u.$$

Condition 3 further implies that the producer's payoff from honesty should equal or exceed that from cheating. Let V_h be the payoff of the producer who receives high quality and pays a high price and V_l be the payoff of the producer who receives low quality and pays a low price. Also let V_u be the payoff of a producer who is currently unmatched and V be the prior expectation of return to the producer who has been matched but has not yet received any supply. Then

$$V_h = P_H - r - p_h + \delta \{ \gamma V_h + (1 - \gamma) V_u \}$$

$$V_l = P_L - r - p_l + \delta \{ \gamma V_l + (1 - \gamma) V_u \}$$

$$V_u = \delta \{ qV + (1 - q)V_u \}.$$

From these, we have

$$V_h = \frac{P_H - r - p_h + \delta(1 - \gamma)V_u}{1 - \delta\gamma}$$

$$V_l = \frac{P_L - r - p_l + \delta(1 - \gamma)V_u}{1 - \delta\gamma}$$

$$V_u = \frac{\delta q}{1 - \delta(1 - q)} V$$

Further, in equilibrium, the producer correctly expects the quality of supply to reflect that of labor skills; thus, the probability of high quality supply corresponds to the proportion (say λ) of skilled labor and

$$V = \lambda V_h + (1 - \lambda)V_l.$$

In this scenario, producers can cheat only by paying a low price for high quality, whereupon the supplier terminates the relationship and the producer has to search for a new match. The payoff to a one-period deviation of this kind is

$$V_d = P_H - r - p_L + \delta V_u.$$

We require

$$V_h \geq V_d.$$

We can find what this implies in terms of the input and output prices, combine the findings with the condition for suppliers to be indifferent between supplying high quality and low quality and use the Nash bargaining condition for determination of transfer prices to derive labor market equilibrium values for skilled and unskilled wages. If these

values are positive, such an equilibrium exists where labor of both skill levels is employed. We do this calculation in the appendix to show that under certain conditions, unskilled wages – and therefore skilled wages as well – can indeed be positive. However, this is by no means a certainty.

Thus in general equilibrium, adjustments in the labor market will change wages and transfer prices in such a way that we are at the border between a high quality honest equilibrium and a low quality one : in fact, both high and low quality will in general co-exist in equilibrium, as long as labor of both kinds exists in the economy, unless of course the equilibrium wage for unskilled labor is negative – or, as may be easily generalized, below a minimum subsistence requirement. In the latter case, the model will generate unemployment. From our calculations in the appendix it is easy to show that unemployment of unskilled labor becomes likely if the probability of exogenous separations is very high or if agents are very impatient, as in these circumstances the unskilled labor wage consistent with employment of both types of labor in general equilibrium becomes too low to be feasible (in this case, negative).

5. Conclusion

We have applied three models to the analysis of repeated interactions between homogeneous (optimizing) input suppliers and heterogeneous final goods producers (who can be either optimizing, or can follow the behavioral rule of always being honest) where input quality is non-verifiable, producers face uncertain search and deliberate termination of a match constitutes the main threat against cheating. There is absence of collective information or memory about cheating. Unlike many other papers, we do not consider random i.i.d matches every period, but allow relationships to persist in the absence of exogenous separation or deliberate termination. In our first model, all factors are in elastic supply and wages and product prices are exogenous : we characterize conditions supporting (a) a high-quality honest equilibrium, (b) a high-quality equilibrium where opportunists cheat, (c) a low-quality equilibrium, and (d) a region of multiple equilibria. We show that returns to cheating are increasing in the proportion of behavioral players in the population of producers. In our second model, we introduce competition between

producers for an inelastic factor, working capital. We show that in many parameter ranges this generates adverse selection, eliminating some (but not all) behavioral players – but while limiting the proportion of intrinsically honest players, the strategic response of input suppliers ensures that universal honesty is enforced. This provides an example of what happens when strategic and behavioral players belonging to the same class of agents compete while simultaneously playing a game against another class of agents. While some “unfit” players may be weeded out, the strategy of these unfit players becomes universally prevalent owing to the strategic response of the other class of agents. This response also limits the extent to which “selection” is allowed to operate : not all behavioral types are eliminated. We also argued that the presence of this channel of competition could serve as an equilibrium selection device eliminating the multiplicity of equilibria which obtained for some parameter ranges in the first model. In the second model, cheating never takes place in equilibrium, and we have either a high quality honest equilibrium or one with low quality. In our third model, we endogenize wages of skilled and unskilled labor whose supply we assume to be inelastic so that the wages are demand-determined. We showed that in general both types of labor are employed in general equilibrium which constitutes a border between high and low quality equilibria – both high and low quality are supplied and produced in equilibrium and there is no cheating. However, if exogenous separation is likely or if agents are impatient, it is possible to have involuntary unemployment of unskilled labor in general equilibrium so that high quality alone is produced and only skilled labor is employed.

Appendix A : Calculation of the threshold α^*

Given that opportunistic producers have an incentive to cheat (i.e, (16) holds), when suppliers observe producers on the market, the conditional probability they assign to such a producer’s honesty is given by $\frac{\alpha(1-\gamma)}{1-\alpha\gamma}$. The numerator shows the probability that the producer is an honest type whose match terminated exogenously (all producers whose matches were deliberately terminated are of course opportunistic). The denominator shows the probability of a producer’s being on the market. Now we denote by $V(HQ)$ the supplier’s payoff to following the strategy of offering high quality:

$$\begin{aligned}
V(HQ) &= \frac{\alpha(1-\gamma)}{1-\alpha\gamma} \left[\frac{p_H - w_s}{1-\delta\gamma} + \frac{\delta(1-\gamma)}{1-\delta} V(HQ) \right] + \frac{1-\alpha}{1-\alpha\gamma} [p_L - w_s + \delta V(HQ)] \\
&= \left[\frac{1-\delta}{(1-\alpha\gamma)(1-\delta) - \alpha\delta(1-\gamma)^2 - \delta(1-\alpha)(1-\delta)} \right] \left[\frac{\alpha(1-\gamma)(p_H - w_s)}{1-\delta\gamma} + (1-\alpha)(p_L - w_s) \right]
\end{aligned}$$

By offering low quality, on the other hand, suppliers get:

$$V(LQ) = \frac{p_L - w_u}{1-\delta\gamma} + \frac{\delta(1-\gamma)}{1-\delta} \frac{p_L - w_u}{1-\delta\gamma}$$

where the first term simply shows that the supplier gets the low quality payoff if the match does not break off exogenously, and the second term shows that if the match breaks off exogenously in any future period, the supplier again gets the low quality payoff in a new match. This simplifies to

$$V(LQ) = \frac{p_L - w_u}{1-\delta}$$

Thus whenever (18) holds, a supplier supplies high quality if and only if $V(HQ)$ exceeds $V(LQ)$. This happens for a threshold level of α given by

$$\alpha^* = \frac{w_s - w_u}{\frac{1-\gamma}{1-\delta\gamma} (p_H - w_s) - (p_L - w_s) + \frac{(p_L - w_u)}{1-\delta} \left\{ \gamma - \delta + \frac{\delta(1-\gamma)^2}{1-\delta} \right\}} \quad (19)$$

Appendix B : Equilibrium probability of successful search in Model 2

In our second model, some intrinsically honest producers may leave the market in case α started out being higher than α^* and if parameters were such that opportunistic producers had an incentive to cheat. In this case, let d be the number of honest producers who “die” or leave the market as a result of competition. Now d solves

$$\frac{\alpha N - d}{N - d} = \alpha^*$$

where N was the initial number of producers, and α the initial fraction of intrinsically honest producers. Then in equilibrium, where we necessarily have honesty, the relevant probability of successful search is now given by

$$q_H = \frac{M(1-\gamma)}{N-d-\gamma M}$$

However, if α started out being lower than α^* , no “deaths” owing to competition take place and the probability of successful search remains the same as the q_H of Model 1. The same is true if parameters are such that a high quality honest equilibrium is sure to obtain and no one has an incentive to cheat – as there is no destructive competition in this case either.

Appendix C : Derivation of Wages Consistent with General Equilibrium (Model 3) with both types of labor being employed

We write P_h for $P_H - r$ and P_l for $P_L - r$ in order to slightly simplify the notation. For opportunistic producers not to want to cheat when supplied high quality, we require

$$V_h = \frac{P_h - p_H + \delta(1-\gamma)V_U}{1-\delta\gamma} \geq V_d = P_h - p_L + \delta V_U$$

Simplifying, this amounts to

$$\delta\gamma(P_h - p_L) \geq \delta\gamma(1-\delta)V_U + p_H - p_L$$

Substituting for the transfer prices, using

$$p_H = \frac{P_h + w_s}{2}, p_L = \frac{P_l + w_u}{2}$$

we get

$$\delta\gamma\left(P_h - \frac{P_l}{2} - \frac{w_u}{2}\right) \geq \delta\gamma(1-\delta)V_U + \frac{(P_h - P_l) + (w_s - w_u)}{2} \quad (\text{A1})$$

But we also have

$$P_H - w_s = P_L - w_u$$

Or

$$\frac{P_h - w_s}{2} = \frac{P_l - w_u}{2}$$

$$\Rightarrow P_h - P_l = w_s - w_u. \quad (\text{A2})$$

Also

$$P_h - p_H = \frac{P_h - w_s}{2} = \frac{P_l - w_u}{2} = P_l - p_L \quad (\text{A3})$$

From (A2),

$$\delta\gamma\left(P_h - \frac{P_l}{2} - \frac{w_u}{2}\right) \geq \delta\gamma(1-\delta)V_U + P_h - P_l. \quad (\text{A4})$$

From (A3),

$$V_h = V_l = V.$$

So

$$V_U = \frac{\delta q V_h}{1 - \delta(1-q)} = \frac{\delta q}{1 - \delta(1-q)} \left[\frac{\{(P_h - w_s)/2\} + \delta(1-\gamma)V_U}{1 - \delta\gamma} \right]$$

or

$$V_U = \frac{\delta q}{(1-\delta)(1+\delta q - \delta\gamma)} \left(\frac{P_h - w_s}{2} \right) \quad (\text{A5})$$

From (A4), (A5) and (A2),

$$\delta\gamma\left(P_h - \frac{P_l}{2} - \frac{w_u}{2}\right) \geq \frac{\delta^2\gamma q(P_l - w_u)}{2[1+\delta q - \delta\gamma]} + P_h - P_l$$

Solving,

$$w_u \leq \frac{[2 + 2\delta q - 3\delta\gamma - 2\delta^2\gamma q + \delta^2\gamma^2]P_l - [2 + 2\delta q - 4\delta\gamma - 2\delta^2\gamma q + 2\delta^2\gamma^2]P_h}{\delta\gamma(1-\delta\gamma)}$$

w_u can be positive only if the right hand side of the above inequality is positive. This requires that

$$P_l \frac{2(1+\delta q) - \delta\gamma}{\delta\gamma} - P_h \frac{2(1+\delta q) - 2\delta\gamma}{\delta\gamma} > 0$$

$$\text{Or } P_l/P_h > \frac{2(1+\delta q) - 2\delta\gamma}{2(1+\delta q) - \delta\gamma} = 1 - \frac{\delta\gamma}{2(1+\delta q) - \delta\gamma}.$$

The right hand side of this inequality is decreasing in δ and γ and increasing in q . For a given configuration of product prices, a positive w_u is likelier the lower the exogenous separation probability and the lower the discount rate and the prospect of finding a new match in the next period (the latter being in turn an increasing function of the separation probability). A positive w_u in equilibrium implies of course full employment of unskilled, as well as skilled, labor. Conversely an equilibrium with involuntary

unemployment of unskilled labor is more likely if the probability of exogenous separation is very high or if agents are very impatient.

$$w_s = w_u + P_h - P_l$$

$$\text{or } w_s \leq \frac{[2 + 2\delta q - 4\delta\gamma - 2\delta^2\gamma q + 2\delta^2\gamma^2]P_l - [2 + 2\delta q - 5\delta\gamma - 2\delta^2\gamma q + 3\delta^2\gamma^2]P_h}{\delta\gamma(1 - \delta\gamma)}$$

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