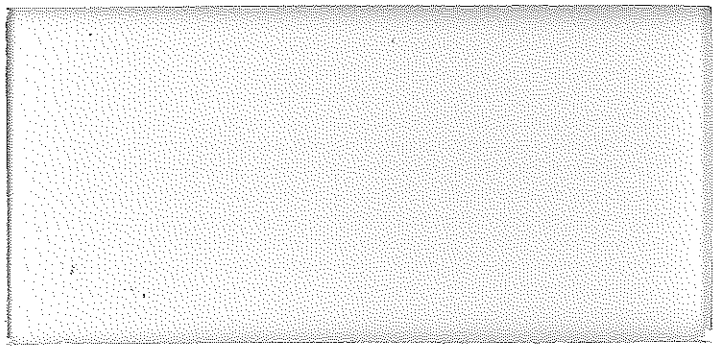
UNIVERSITÀ DEGLI STUDI DI ANCONA
DIPARTIMENTO DI ECONOMIA

TECHNOLOGY ADOPTION UNDER STRATEGIC COMPLEMENTARITY: "LESS" INFORMATION CAN DO BETTER

STEFANO MANZOCCHI *, DOMENICO MARINUCCI **

QUADERNI DI RICERCA n. 37



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Abstract

Strategic complementarities can lead to multiple Nash equilibria in macro-economic models. When this is the case of a decentralized economy, agents have to choose their strategy on the basis of the expected behaviour of other agents, but the concept of rational expectations is not a guide to selecting among multiple Nash equilibria.

Our point is that perfect observation without coordination can lead to less efficient outcomes in a specific example of "coordination game", where the Nash equilibria can be Pareto-ranked and expectations are "backward-looking".

1) Introduction

The search for "first principles" aimed to a new and more solid foundation of Keynesian economics has pointed out to the issue of coordination among agents in a market economy as a key question for macro-economics (see Mankiw and Romer, 1991). Recently, there have been attemps to extend the scope of coordination problems and failures to the economics of intertemporal allocation and growth (see De La Fuente, 1990).

Once the relevance of coordination problems has been proved, however, theoretical research should be oriented towards the study of feasible solutions for these problems, i.e. how rational agents can possibly overcome a coordination failure. This seems to be a more difficult topic to address, because there is no simple (and univoque) solutions for problems of market failure provided one neglects the central planner solution (which is appearently out of fashion nowadays). Hence, trying to model how individuals can solve coordination problems is a fascinating but risky task (the risk being that of ad-hoc assumptions and inconclusive conclusions).

There are two main categories of solutions in models of coordination among economic agents:

a) solutions which emerge whenever some type of interaction is possible among agents before they make their individual choices in the market;

b) solutions which occur whenever each agent always finds himself in isolation, and has to form his beliefs and make his choices without previously interacting with other agents.

The first category includes solutions belonging to the literature on bargaining: for instance, Binmore and Dasgupta (1987, p.5) clearly state this feature of bargaining games:

"(They are) games which are to be analysed on the assumption that some measure of pre-play interaction between players is possible".

Solutions of the coordination problem which are derived under the hypothesis of mere pre-play communication among agents also belong to the first category. The distinction between a "bargaining" situation and a mere "communication" context hinges on the concept of "binding

agreement": binding agreements (or committments) are required to obtain a negotiated solution in bargaining games ([1]), while equilibria of a different nature can be achieved under the assumption of non-binding communication.([2]) Therefore, we could say that "communication" consists of a weaker kind of pre-play interaction than "bargaining".

It has been shown by Farrell (1987) that costless, non-binding announcements ("cheap talk") made by agents in a non-cooperative setting helps reducing the prohability of a coordination failure, provided agents actually play the announced (pure) strategies if they constitute a Nash equilibrium. Another interesting result is that extending the scope of "cheap talk" from a single round to a multi-stage communication game does not eliminate coordination failures, whenever selection among multiple Nash equilibria involves some degree of conflict among economic agents (see Farrell, 1987, p.39).

Cooper et al. (1990) analyse the role of communication in a different class of games, so-called "coordination games": the peculiar feature of these games is that they do not involve conflict among agents in the process of equilibrium selection, because the multiple Nash equilibria can be Pareto-ranked. Hence, the source of coordination failures in this class of games is pure strategic uncertainty rather than conflict: strategic uncertainty is the sole responsible for the "riskness" associated with the strategy supporting the Pareto-superior equilibrium.([3])

In a subsequent contribution, Cooper et al. (1992) suggest that different communication structures are needed to (partially) overcome coordination failures in different types of games, and provide experimental evidence on this point. They recognize, however, that their work is not suited to describe a macro-economic environment, where a large number of individuals interact in the market and where the hypothesis of costless communication would be irrealistic.([4])

In this paper, we want to pursue another approach to coordination problems: this approach is related to the second category of solutions mentioned above. We believe that, in the absence of

[1] Binmore (1987), p.29.

[2] Farrell (1987), p.37.

[3] Cooper et al. (1992), p.766.

[4] Cooper et al. (1992), p.742 ft.3.

efficient communication among economic agents (due to the fact that communication is costly and difficult to implement in a many-person decentralized economy), individuals have to rely on other types of informations in order to choose their strategies. Viewed from a different perspective, we take the scenario of a decentralized economy to its ultimate consequences, as done for instance by Meyer et al. (1992), and allow no pre-play interaction among agents: it is just the "structure" of the economy that establishes linkages through a large number of individuals.

How do agents behave in case of coordination problems when no pre-play interaction is feasible? On the one hand, individuals have to form their beliefs and make their choices in isolation and, of course, they try to reduce the burden of strategic uncertainty making the best possible use of all relevant information available to them. On the other hand, information is a scarce and costly resource.

The controversy on "rational expectations" must be re-considered here for two reasons: firstly, the assumption of "substantive rationality" and "rational expectations" has a limited application in this context, because it is of no help in selecting among multiple Nash equilibria.([5]) In a context of decentralized producers who decide the quantity to be supplied based on past market prices, Guesnarie (1992) proves that a unique Nash equilibrium is the only "rationalizable" equilibrium, that is the equilibrium selected under the hypotheses of rational expectations and common knowledge of rationality. However, every Nash equilibrium is "rationalizable", hence the assumption of rational expectations cannot be used to select among Nash equilibria (p. 1257-58).([6])

Indeed, it has been shown by Krugman (1991) that the solution of a model of intertemporal allocation decisions, in which externalities are a relevant feature and coordination failures may arise, depends on whether "expectations" or "history" prevail i.e. whether agents form their beliefs assuming that other agents will behave differently from the past, or not. "Substantive" rationality does not seem to be an adequate concept for elaborating on this point, once the preliminar step of identifying the conditions under which multiple solutions emerge has been accomplished.([7])

[5] See Simon (1976) for the distinction between "substantive" and "procedural" rationality.

[6] On the concept of "rationalizable" equilibria in games with strategic complementarities, see also Milgrom and Roberts (1990).

[7] See Krugman (1991), p.664.

Secondly, whenever information is scarce and costly some concept of "bounded rationality" can be more adequate. From the point of view of "bounded rationality", one can perhaps make some progress in the investigation of equilibrium selection under strategic uncertainty. Let us go back to the issue of coordination problems when individuals are in isolation: in general, they have to form an expectation on how many fellow individuals will choose a particular strategy in the future. The questions are: what is the relation between their expectations and the outcomes of the past? In other words, how does "history" affect "expectations"? Moreover, how much information will be collected by rational agents, provided it is not a free good?

Of course, we do not mean to offer any general answer to such complex and fundamental questions. More realistically, we are interested in studying the conditions for a "non-coordinated" solution in a specific problem of coordination failure, a problem similar to the one suggested by Krugman (1991). Suppose that individuals have static expectations in the sense that each agent believes that each other agent will not change his behaviour in the future: in this case, it would seem that "history" can univoquely determine the outcome (in other words, perfectly "static" expectations in this context that are consistent with a Nash-type behaviour, which can yield coordination failures).([8])

However, agents in isolation can make mistakes in observing the strategies chosen by all other individuals, simply because direct communication among all agents is ruled out and collecting information about current behaviours is costly: therefore, each agent observes the current strategies of other agents with an error.([9]) We show that this kind of errors can indeed be helpful in the process of transition from an "old" to a "modern" production technique, where the latter is characterized by increasing returns due to "network externalities".

2) The model

In an intertemporal model, an economy can get stuck in a "coordination-failure" equilibrium

[8] On this point, see Cooper and John (1988).

[9] We simply assume the existence of this observation error, and we are aware of many possible critiques that can be addressed towards this assumption.

because of the combination of three main elements:([10])

1) the existence of strategic complementarities among agents (are defined by Cooper and John [1988]);

2) the absence of coordinating devices (such as "communication" as meant by Farrell) in a decentralized economy;

3) the assumption that each individual has perfect knowledge of the current production strategies of all other individuals, although the game is one of "imperfect information" because in each period all individuals choose their future strategies simultaneously.

The existence of multiple, Pareto-ranked "Nash symmetric equilibria" depends on element 1), while elements 2) and 3) provides the rationale for an economy being trapped in a "low-level" equilibrium (i.e. a macro-economic coordination failure).

In our view, element 3) is a very strong hypothesis in this case. In a decentralized economy, where communication among agents is ruled out, why should we assume that each individual perfectly knows the current production strategies of all other people?

Our model follows that of Krugman (1991) in assuming that the only argument of the individual's objective function is current and future income. We consider a two-period, one-sector economy which produces a single commodity by means of a single homogeneous factor (labour). The price of the commodity is fixed at its international level; in what follows, we assume it is equal to one. There exist two different methods of production, labeled T and M. The former is a traditional, constant-returns-to-scale technique: labour productivity is fixed.

"M" is a modern technique: due to "network externalities", the average labour productivity of technique M is an increasing function of the number of producers adopting it.([11])

We are in a completely decentralized economy, so that there is a one-to-one correspondence

[10] Examples are provided in Manzocchi (1993).

[11] See Katz and Shapiro (1985) on the meaning of "network externalities"; Farrell and Saloner (1985) consider "network externalities" in games of sequential (rather than simultaneous) decisions.

between workers and "firms": therefore, there exists no labour market and each worker earns the value of its average product. Our macro-economy consists of a "very large" number of identical agents (N) ("very large" is defined in the Appendix as large enough to allow the approximation of a binomial by a normal distribution).

In the first period, each producer faces the choice of the production technique for the future period; we assume that she has to incur a "sunk" cost γ to switch from technique T to M. γ (the unit adjustment cost) can be viewed as the cost for each individual of the "training" required to use the modern technique; this cost has to be payed in the current period in order to adopt M in the next one.

An individual, representative agent maximizes the discounted value of her income at time t, which is equal to (V_t):

$$V_t = W_t + \frac{W_t}{1+\theta} \qquad (1)$$

if she adopts the traditional technique in the first period, and keeps adopting it in the second one. W_t is the average product of labour with the traditional technique in period t, θ is the rate of intertemporal discount (which could be set equal to the international rate of interest, as in Krugman (1991)).

Whenever a worker decides to shift from the traditional to the modern technique, the discounted value of her income is equal to (V'_t):

$$V'_t = W_t - \gamma + \frac{i_{t+1}^{\alpha} + W_t}{1+\theta} \qquad (2)$$

where i_t is the number of workers adopting the modern technique in period t; we assume that the "virtual" average productivity of the modern technique is equal to W_t when it is not yet adopted by any producer. The presence of increasing returns due to network externalities is captured by the (positive) coefficient α.

Under the above assumptions, a worker who decided in period (t-1) to adopt the increasing returns technique in period t has no incentive to go back to the traditional one, even if there are no "adjustment costs" in moving from the modern to the traditional technique and regardless of how many other fellow workers choose the modern technique. The decision process of that kind of producer is trivial, and we neglect it: we could say that the adoption of the modern technique is irreversible, once the sunk cost γ has been payed.

The payoff matrix of an individual worker that is adopting technique T in the first period is conditional on the strategy of the other (N-1) workers (see figure 1). This matrix has some resemblance with those by Manzocchi (1993): like there, we have two Nash symmetric equilibria, one where all agents choose strategy T and one where they all choose M.

We consider the case in which both techniques initially co-exist: this is equivalent to assume that - in period t - i_t is strictly positive (otherwise technique "M" would have not yet been introduced in the actual economy).

As there is no labour market, an individual cannot observe a market wage rate; we assume that agents know that the modern technique is characterized by external economies of scale, and take decisions for period (t+1) based upon their observations of how many workers choose "M" at time t (i.e., they have static expectations); this observations are, though, not perfect, since they are distorted by an unbiased error ϵ log-normally distributed, identical across agents:[12]

$$E(i_{t+1}) = \epsilon i_t \; ; \quad \ln\epsilon \sim N(0,\sigma_\epsilon^2) \qquad (3)$$

Therefore, the individual's observed payoff matrix looks like figure 2. We then introduce the following:

[12] We assume that the decision rule of the individual agents is "common knowledge" (of course, agents are not aware of the existence of an observation error).

Definition:

"A superior technique is the one that yields the higher discounted value of personal income".

It is straightforward to verify that the modern technique M is superior if and only if condition (4) holds:

$$i_{t+1} > i^* \qquad i^* = \min i_t : i_t \geq [\gamma(1+\theta)]^{\frac{1}{\alpha}} \tag{4}$$

where γ and θ are given (finite) numbers. By simple substitution, in fact, we have:

$$i_{t+1} \geq i^* \Rightarrow V_t' > V_t \tag{5}$$

Hence, the modern technique is more profitable of the traditional one even including the sunk costs incurred to change production technique.

It is easy to see that when all the workers in the economy adopt strategy "M", the discounted value of personal income is higher than the value when all the workers choose strategy "T". Hence, the symmetric Nash equilibrium corresponding to the complete diffusion of technique M is Pareto-superior to the other one where only technique T is adopted: this is a pre-condition for the emergence of a coordination failure.

Our result can then be stated as follows:

Proposition:

"Under the above assumptions, the probability that the modern technique becomes 'superior' is an increasing function of the variance of the error of observation of the agents."

The complete demonstration of this proposition is reported in the Appendix. Let us discuss the economic interpretation of this result. Under certainty, if the number of agents who adopt M at time t is positive but below the "threshold" level required to make the modern technique profitable, the probability for M to become the "superior" technique is zero, as an individual agent recognizes that her discounted income will decrease if she adopts M in the future period.([13])

In a model with perfect knowledge, this economy would be captured in a (Pareto) inefficient equilibrium; in fact, since each agent (who is adopting the traditional technique at time t) observes that the number of workers adopting the modern technique is not large enough to make it profitable for her to shift, she will stick to the constant-returns-to-scale technique.

The hypothesis of an observation error plays a key role in providing a "solution" to the coordination problem and increasing the probability of a productivity gain. What may happen is that a number of agents, on the basis of wrong observations, estimate it profitable to shift to the modern technique; if this number is large enough to overcome the threshold value which makes "M" "superior", moving to the modern technique will actually become the best possible strategy.

When the variance of the observation error increases, the probability for an individual agent of choosing the modern technique grows: even if each individual is risk-neutral, the structure of the model is such that an appearently "risk-oriented" behaviour emerges in the aggregate.

[13] A proper question is: "Why are some agents already using technique M in period t?" Our answer is that we study the probability that M becomes the "superior technique" given some initial conditions (particularly, on i_t): under our assumptions, it is clear that the probability is zero whenever $i_t = 0$, no means how large is the variance of the error. A case where our analysis holds is the following: suppose a guy comes back home after 10 years with his knowledge of technique M learned abroad; now our story can start. (Why did he come back? He wants to marry Her!).

3) Concluding remarks

The aim of this article is to offer some preliminary reflections on the outcomes of macro-economic "coordination games", that is games where there is no conflict among agents, but only strategic uncertainty in the process of equilibrium selection.

It has been shown in the literature that costless, non-binding communication can help solving coordination problems with a limited number of players; however, the scope of these results cannot be extended to many-players, decentralized economies. If one is faced by coordination failures in macro-economic models, in which communication is costly and difficult to implement, a careful analysis of the process of expectation formation is required.

In this case, the concept of "substantive rationality" (or "rational expectations") is neither helpful (it does not really help selecting an equilihrium) nor appropriate (collecting information in a decentralized economy with no central authority must be modelled as a costly activity): hence, "bounded rationality" appears to be a better-suited concept, although we do not proceed here any further along the way of defining "what" bounded rationality is. Our point is simply that perfect observation without coordination can lead to less efficient outcomes in specific examples of "coordination games". In other words, observation errors are likely to favour, rather than prevent, the selection of superior equilibria under our assumptions.

Put in another perspective, this paper shows an application of the second best principle: a market failure is generated here by the assumption of production externalities, and in the absence of a coordination device providing the "public good" of a common strategy, second best solutions are found when agents have "less" (or, better, less accurate) information. Although the Pareto optimum may not be attainable in a finite interval of time in the presence of "noise", the probability of the external-economies-of-scale technique being adopted by a large enough number of agents rises with the variance of the observation error.

In terms of "public economics" the message of this paper can be summarized as follows: any improvement in the quality and quantity of information available to individuals must he counterbalanced by the creation or refinement of coordination institutions, whenever potential "social" henefits from technical change exist in a decentralized economy like ours.

Although our hypotheses are quite restrictive, we think that our result should hold even allowing for a more complex mechanism of expectations formation: in particular, it should be possible to demonstrate that the same conclusion apply whenever the expected value of i_{t+1} is a non-decreasing function of the observed value at time t (i.e. adaptive or extrapolative expectations); in the same way, extending the model from a two-period to a multi-period framework should only make the maths more complex, without altering the qualitative results. Anyway, these statements can be viewed as suggestions for further research.

4) Appendix

Proof:

Let H be

$$H=P(i_{t+1}>i^*/i_t) \quad ; \quad i_t < i^* \tag{6}$$

that is, the probability to overcome the threshold value at time t+1, given i at time t.

Besides, let G he

$$G=P(\frac{(\epsilon i_t)^{\alpha}+W_t}{1+\theta}+W_t-\gamma>W_t+\frac{W_t}{1+\theta}) \tag{7}$$

that is, the probability that a single agent finds it profitable to shift to the modern method of production. Our proof will then be in two steps:

1) prove that:

$$1)\ \frac{dG}{d\sigma_\epsilon^2} > 0 \tag{9}$$

2) prove that:

$$2)\ \frac{dH}{d\sigma_\epsilon^2}=\frac{dH}{dG}\frac{dG}{d\sigma_\epsilon^2} > 0 \tag{10}$$

that is, given (9):

$$\frac{dH}{dG} > 0 \tag{10}$$

Let us prove inequality (9):

$$G = P\left(\frac{(\epsilon i_t)^\alpha + W_t}{1+\theta} - \gamma + W_t > W_t + \frac{W_t}{1+\theta}\right) \tag{11}$$

which can be expressed as

$$P\left(\frac{(\epsilon i_t)^\alpha}{1+\theta} > \gamma\right) = P\left(\epsilon > \frac{(\gamma(1+\theta))^{\frac{1}{\alpha}}}{i_t}\right) \tag{12}$$

Since ϵ is log-normally distributed, we can rewrite G as:

$$\int_{\frac{1}{\alpha}\ln(\gamma(1+\theta))-\ln i_t}^{\infty} (2\pi)^{-\frac{1}{2}} e^{-\frac{1}{2}x^2} dx \tag{13}$$

σ_ϵ^2

Then:

$$\frac{dG}{d\sigma_e^2} = -(2\pi)^{-\frac{1}{2}}\left(-\frac{1}{\sigma^4_e}\right) e^{-\frac{1}{2}x^2}\left\{\frac{1}{\alpha}\ln[\gamma(1+\theta)] - \ln(i_t)\right\} \tag{14}$$

that implies, since the first two terms are negative and the second two positive:

$$\frac{dG}{d\sigma_e^2} > 0 \tag{15}$$

and thus, the first step of our proof is completed; as far as the second is concerned, it is easy to see that H can be expressed as follows:

$$\sum_{i=i^*-i_t}^{N-i_t} \binom{N-i_t}{i} G^i (1-G)^{N-i_t-i} \tag{16}$$

By the De Moivre-Laplace Theorem, we have that:

$$\lim_{N\to\infty} H = \int_{\frac{i^*-i_t-MG}{\sqrt{MG(1-G)}}}^{\infty} (2\pi)^{-\frac{1}{2}} e^{-\frac{1}{2}x^2} dx \qquad with \quad M = N - i_t \tag{17}$$

(The limit of a binomial distribution with parameters G and M is a normal distribution with mean MG and variance MG(1-G)).

We may then rewrite:

$$\frac{dH}{dG} = \frac{d(1-F(y))}{dy}\frac{dy}{dG} \quad with\ y = \frac{A-MG}{\sqrt{MG(1-G)}} \quad ; \quad A = i^*-i_t \tag{18}$$

where F(.) is the distribution function. Equation (18) can be re-arranged as:

$$\frac{dH}{dG} = \left(-\frac{dF(y)}{dy}\right)\frac{dy}{dG} \tag{19}$$

It is evident that the first term of the right hand side of (19) must always be negative; our Proposition will therefore be proved if we show that (dy/dG)<0. We have:

$$\frac{dy}{dG} = \frac{-M^2G(1-G)-(A-MG)(M-2MG)}{M^2G^2(1-G)^2} \tag{20}$$

which is negative if and only if:

$$M^2G(1-G) + (A-MG)(M-2MG) > 0 \tag{21}$$

that is:

$$M^2G^2 + AM - 2MAG > 0 \tag{22}$$

Two cases are therefore possible:

$$a) \quad G \le \frac{1}{2}$$

then we have:

$$M^2G^2 + AM - 2MAG > M^2G^2 + AM - 2MA\left(\frac{1}{2}\right) = M^2G^2 > 0 \tag{23}$$

$$b) \quad G > 1/2;$$

then we have:

$$M^2G^2 + AM - 2AMG \tag{24}$$

(24) is a decreasing function of A; it will reach its minimum value when A is maximum (A = M). Hence, the minimum is equal to:

$$M^2G^2 + M^2 - 2M^2G = M^2(G^2+1-2G) = M^2(1-G)^2 > 0 \qquad (25)$$

and since it is larger than zero, the whole function is always positive. Q.E.D.

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Number of other agents adopting technique M

Agent n's strategy	O	i
T	$W_t + \frac{W_t}{1+\theta}$	$W_t + \frac{W_t}{1+\theta}$
M	$W_t - \gamma + \frac{W_t}{1+\theta}$	$W_t - \gamma + \frac{W_t + j^e_{t+1}}{1+\theta}$

Figure 1: Pay-off matrix of agent n

Number of other agents adopting technique M

Agent n's strategy	O	I
T	$W_t + \frac{W_t}{1+\theta}$	$W_t + \frac{W_t}{1+\theta}$
M	$W_t - \gamma + \frac{W_t}{1+\theta}$	$W_t - \gamma + \frac{W_t+(ei_t)^a}{1+\theta}$

Figure 2: Observed pay-off matrix of agent n

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