Complementarities and Information*

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The study of economies and markets with dispersed information has attracted a lot of attention at least since the pioneering work of Radner (1979) and Grossman (1989). The importance of informational efficiency in markets is well understood (Vives, 2008). At the same time, and relatively more recently, the analysis of complementarities has been pushed forward with box of tools provided by the theory of supermodular games (Vives, 1985, 1990), Milgrom and Roberts (1990 a, b), and Vives (2005) for a recent survey including Bayesian games). In many situations complementarity patterns interact in a rich way with information structures and provide insights into the workings of the economy. The papers present the state of the art in the field and span from theory to empirics and experiments, from the analysis of markets to the analysis of organizations.

***George-Marios Angeletos* and *Alessandro Pavan,* "Policy with Dispersed Information".**

George-Marios Angeletos and *Alessandro Pavan* analyze economies in a linear quadratic framework with private information. The objective is to design taxation instruments contingent on ex post public information on fundamentals and aggregate activity to improve market allocations when the government cannot observe the dispersed information agents have on aggregate shocks. The idea of using Pigouvian taxes to correct for inefficiencies in the use of information, on top of payoff externalities, is natural. The authors find that with private information on aggregate shocks to condition on the level of aggregate activity is crucial to attain efficiency. This in contrast to the cases of symmetric information or pure private values -with information on idiosyncratic shocks- where it is enough to condition on the realized fundamentals to obtain efficiency. Indeed, the imposition of taxes based on ex post realizations changes the incentives agents face. If an agent expects marginal taxes to increase with fundamentals it will tend

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to respond less to any source of fundamentals information. If an agent expects marginal taxes to increase with aggregate activity the agent will tend to rely less on information signals which have more correlated noise since he will perceive less complementarity in his action with the actions of others (the link is that more correlated signals help to forecast the actions of others better). By choosing appropriate tax weights on ex post fundamentals and aggregate activity tax policy can be designed to restore the efficient use of information. In particular, the authors show that the impact of noise on equilibrium activity can be reduced without dampening the influence of fundamentals.

The paper builds on a static linear-quadratic model where the payoff to an agents depends on own action, average action and its dispersion, plus an idiosyncratic shock and its average. The efficiency concept used is team-efficiency where the planner can recommend each agent a strategy which depends only on the information the agent has. A key element of the equilibrium characterization is the equilibrium degree of strategic complementarity α in relation to the efficient one α^* (basically, the slope of the best response of a player in relation to the aggregate action). With only aggregate shocks and a Gaussian structure it is found that the signal to noise ratio in aggregate activity is inefficiently high if and only if $\alpha > \alpha^*$ (all this is linked to overreaction to sources of information with correlated noise and excessive non-fundamental volatility). The authors go on to introduce corrective taxes (contingent on individual action, the average action and its dispersion, as well as the average fundamental) and show the need to use marginal taxes contingent on the level of aggregate activity to implement an efficient allocation when there is private information. The results are robust to introducing measurement error in the government's observation. Finally, a dynamic model is analyzed where both payoff and information externalities are present in a Gaussian information structure where agents observe noisy public signals of past activity, and private and public signals on the common fundamental. This model extends the dynamic learning model of Vives (1997) –and the extension in Amador and Weil (2007) – to encompass payoff externalities. For the efficient solution the authors have to restrict attention to strategies that are linear in the history of private signals. The result, as in Vives (1997) is that the efficient solution calls for extra weight to private information in relation to the equilibrium solution (this is equivalent to requiring agents to perceive a lower degree of strategic complementarity than the equilibrium one). This internalizes the information externality. Finally, it is found that once information is used properly more information can not hurt.

This paper opens the way for the design of policy measures to correct inefficiencies derived from the use of information by agents and is bound to be relevant in a range of applications (business cycles, financial markets, fiscal policy).

Xianwen Shi, Dirk Bergemann **and** ***Juuso Välimäki*****, "Information Acquisition in Interdependent Value Auctions"**

Xianwen Shi, *Dirk Bergemann* and *Juuso Välimäki* contribute to the literature on auctions with endogenous information acquisition. There is a small literature on the topic (see, e.g. Matthews (1984), Stegeman (1996), and Persico (2000)). In their paper each bidder bears a cost to acquire information about her payoff type. Information acquisition decisions are taken simultaneously and covertly before the auction takes place. The authors assume also that values are interdependent, that information acquisition is binary -that is, a bidder can either be uninformed or informed- and that utility is linear. The object is allocated according to a Vickrey-Clarke-Groves mechanism. The authors consider pure and mixed equilibria of the information acquisition game and compare it with the socially optimal solution. The main results are that with positive interdependence, bidders acquire too much information in equilibrium and that the information acquisition decisions are strategic substitutes. In fact, it is shown by example that positive interdependence is not a sufficient condition for the bidders' decisions to be strategic substitutes and thus it is compatible with insufficient information acquisition due to strategic complementarity. Finally, the authors relax some of the main assumptions and it is shown how the results can be extended to a nonlinear environment.

The paper opens the way to policies to correct incentives to acquire information (like participation fees and random assignment of the object). It would be also interesting to consider the case where information acquisition is observable. For a contrast of the two different cases in a Cournot market see Hauk and Hurkens (2001) for the covert case and Vives (1988) and Exercise 8.15 in Vives (1999) for the open case – in this latter case strategic complementarity or substitutability in the market stage translates into strategic complementarity or substitutability at the information acquisition stage.

***Jayant Ganguli* and *Liyan Yang*, "Complementarities, Multiplicity, and Supply Information"**

Jayant Ganguli and *Liyan Yang* consider a noisy rational expectations model in the tradition of Grossman and Stiglitz (1980) and Diamond and Verrecchia (1981) and show that if traders can acquire information about the supply of the stock in addition to its payoff multiple equilibria arise and information acquisition decisions can be strategic complements. They obtain that either there is no linear partially revealing equilibrium or there are two linear partially revealing equilibria. In one equilibrium prices become more informative about the fundamental value as the proportion of informed increases and in the other the opposite happens. The price in the second equilibrium is more informative about the fundamental than in the first equilibrium. The first equilibrium shares the features of the equilibrium in Grossman and Stiglitz (1980) and information acquisition decisions about the fundamental value are strategic substitutes. In the second equilibrium they are strategic complements. This second equilibrium would unstable according to usual price adjustment dynamics. As the correlation between the aggregate endowment shock and the idiosyncratic one tends to zero the first equilibrium converges to the (unique) partially revealing equilibrium in Diamond and Verrecchia (1981).

Multiplicity arises in the Ganguli and Yang model because the individual endowment shock of a trader helps reading information about the fundamental value in the price (which depends on the aggregate endowment shock). A high level of price informativeness is self-fulfilling, for example, since it implies that an informed trader puts less weight on his endowment shock when trying to estimate the fundamental and this translates into a smaller weight to the aggregate endowment shock in the price, making it in turn less noisy. Strategic complementarity in information acquisition may lead to multiple equilibria in the information market. The authors extend the model to allow traders to receive information on both the fundamental and the supply shock (instead of each trader receiving a random shock to his endowment). In this model there are also two linear equilibria and in any one of them information acquisition decisions may be strategic complements or substitutes depending on information parameters. Strategic complementarity occurs because with more informed traders the statistical identification problem for the uninformed may become worse.

This paper adds to the growing literature that introduces strategic complementarities in versions of noisy rational expectations models (see for example, Barlevy and Veronesi (2000), Chamley (2007), Veldkamp (2006) and Chapter 4 in Vives (2008) for a summary of the contributions). It may have interesting implications for a range of issues including the cost of capital for firms. It would be worth exploring the robustness of the results to the case of imperfectly competitive traders.

***Antoni Calvó-Armengol* and *Joan de Martí*, "Information Gathering in Organizations: Equilibrium, Welfare and Optimal Network Structure"**

Antoni Calvó-Armengol and *Joan de Martí* look at information gathering in organizations. While the theory of information aggregation in networks is still in its infancy, there are some interesting contributions in the literature. Bala and Goyal (1998), Gale and Kariv (2003), and DeMarzo, Vayanos, and Zweibel (2003), to mention a few, investigate the diffusion of information in networks and provide results on the convergence of beliefs and the efficiency of information aggregation. While the martingale convergence theorem is a powerful tool for studying convergence, comparative static analysis requires much more structure, preferably a closed-form solution for the equilibrium strategies. Calvó-Armengol and de Martí (2008) provide such a closed-form solution within the familiar quadratic-normal framework.

In this paper, the authors address a question in the theory of teams that combines a coordination problem with a problem of information aggregation. The members of the finite team have symmetric payoff functions that depend both on an underlying state of nature θ and the actions chosen by the other members of the team. More precisely, each team member chooses a scalar action a_i to minimize a weighted average of the action's distance from the state θ and the distance from the actions a_{-i}. Each team member receives a private signal y_i on which he conditions his action a_i.

The authors first study a game without communication. In this game, the players observe only their private signals. Actions are chosen simultaneously and the actions form a Bayes-Nash equilibrium. The relative weights placed on the two loss functions are crucial. If all the weight is placed on the distance from θ, the player can ignore the behavior of the other team members and simply use his private information y_i to predict θ. If all the weight placed is on the distance from the other members' actions, the players can ignore θ and use their signals y_i only to predict what the other team members are doing. When there is a mixture of motives, there is a tradeoff between choosing an action close to θ and choosing one close to a_{-i}. Each player is concerned about what the other players are doing, and so must also think about the other players' beliefs about what other players are doing, and so on. In other words, a player's choice of action depends implicitly on a hierarchy of beliefs.

Because the payoff function is quadratic and the random variables are normally distributed, there is a unique equilibrium of the simultaneous move game. The authors show that the equilibrium actions are a function of what they call a knowledge index, which can be defined in terms of the variance-covariance matrix of the vector of signals y and the relative weights on the distance functions. The knowledge index captures the concerns of the players about predicting θ and the values of a_{-i}, in other words, it captures the hierarchy of beliefs generated by the observation of the private signal y_i. The linearity and uniqueness of the equilibrium strategies allow the authors to derive comparative static properties and show how welfare depends on the parameters of the model.

The model described above has no role for communication. In the second part of the paper, the authors study the flow of information through a network. The communication process is modeled as follows. The possibilities for communication are represented by a network (directed graph). The players to whom a player is directly connected (including the player himself) are called his neighborhood. Each agent now receives a signal that is equal to the average of the private signals in his neighborhood (his own private signal is included in the average). Thus, a player only receives information from other players to whom he is directly connected and that information is a function of the neighbors' private signals and *not* the neighbors' actions or the neighbors' neighbors' signals. In this sense, communication is exogenous, rather than endogenous. This has the advantage of allowing the communication process to be modeled as part of a simultaneous move game, but it is also somewhat restrictive and does not capture the ordinary meaning of communication.

The details of the network structure turn out to be very important. It can be shown by example that adding a extra link may reduce welfare. Specifically, this possibility arises if the quality of the private signals is high relative to the prior information and if the incentive to coordinate with other players is very high. Intuitively, the problem arises because the coordination motive emphasizes the importance of symmetric information. Additional information that leads to asymmetries among players may also lead to miscoordination, so that while the players' ability to predict θ improves, their ability to coordinate declines. While it is difficult to characterize optimal networks in general, in special cases it is possible to show that the optimal network is star-shaped.

There is an interesting exercise at the end of the paper where the authors consider more than one round of communication. At each round, players communicate the average of the signals they have previously received, without taking into account the duplication (i.e., double counting) of information. This "boundedly rational" process is biased, giving more influence to better connected agents, as in DeMarzo et al. (2003), but it does converge and the authors' analysis suggests that the optimal network is a regular (symmetric) one.

There are many interesting directions in which to take this work. One, which the authors mention, is to model communication as a dynamic game. In the static game, players only receive information from their immediate neighbors. To receive information from their neighbors' neighbors requires successive rounds of communication. This has been done by Gale and Kariv (2003) for a model of herd behavior, but the communication involved here is more complex, because the payoff functions are more complex. The form that communication takes can also be endogenized, for example to allow players to send messages about individual private signals and individual actions, rather than averages. In fact, an interesting question, not addressed here, concerns the optimal message to send both from a private and a social point of view.

Communication in a dynamic game requires players to be far-sighted, unless one assumes bounded rationality, and this may make the game harder to analyze. Much of the elegance of the current treatment derives from the linearity produced by the quadratic-normal framework, which may not survive the move to a truly dynamic setup.

Perhaps the most interesting questions concern the application of the model. The authors interpret it as a model of organizational behavior, but offer little justification for this interpretation. Communication in organizations is undoubtedly an important topic, but why it takes the precise form assumed here is not clear. By assuming that communication takes the form of exogenous signals, the authors have ruled out the possibility of design: they allow comparisons among networks, but do not allow comparisons of different message spaces. The present framework may be too rigid to capture the self-designing nature of the firm in which managers consciously try to overcome communication problems by developing new channels of communication and coordination. The Marschak-Radner theory of teams, by contrast, provides a richer and more plausible account of communication.

***Norbert Maier* and *Marco Ottaviani*, "Information Sharing in Common Agency: When is Transparency Good?"**

Norbert Maier and *Marco Ottaviani* study when transparency is good in a common agency model with two principals who offer linear incentives. The context is one where a single agent takes an unobservable action (say, exerts effort) that affects two principals each of whom observes privately a (contractible) signal of effort. Principals are risk neutral, the agent is CARA risk averse, the signals are normal and attention is restricted to linear contracts. The authors compare welfare in this private contracting context with what can be attained in the "transparent" context where principals share their signals. It is shown that transparency may be welfare-enhancing or welfare reducing depending on the alignment of the information and the interests of the principals. With no transparency the principal who observes the higher quality signal can design more powerful incentives for the agent while the principal who cares less for the effort of the agent will tend to provide less incentives. The result, roughly, is that when the quality of signals and the interests of the principals are aligned (i.e. the principal who cares more has also better information) then private contracting is good since it avoids the free-riding that would obtain in a transparent regime (then the slopes of the incentive schemes of principals are strategic substitutes). Otherwise, information sharing will improve welfare. In the model the efficient information regime emerges as an equilibrium outcome when each principal receives affixed share of total surplus generated in the different regimes. The paper has a parallel in the information sharing oligopoly literature, however there the efficient information regime need not emerge in equilibrium (see Chapter 8 in Vives (1999)).

***Eugenio Miravete*, "Competing with Menus of Tariff Options"**

The concept of supermodularity, introduced to economics by Vives (1990) and Milgrom and Roberts (1990a, b), has proven very useful in economic theory, but relatively little has been done to make empirical use of the concept. In this paper, Miravete (2008) undertakes an empirical study of the pricing strategies of carriers in the US cellular telephone industry between 1984 and 1992 in search of evidence of strategic complementarities. More precisely, he is interested in understanding the number of different tariffs offered by carriers in markets where there is a single incumbent and a single entrant.

There is a wide variation in the numbers of tariffs offered, but the correlation is strongly positive. This could be evidence of strategic complementarity or it could be the result of heterogeneity in the different markets. The strategy of the present paper is to develop a method of econometric estimation that allows one to control for observed and unobserved heterogeneity. More precisely, Miravete represents the discrete, data-generating process using a Gaussian copula function with double Poisson marginal distributions. This model accommodates the observed underdispersion (positive correlation) in the numbers of tariffs, but also allows for negative correlation. The flexibility of the model is one of its chief advantages. By contrast, the multivariate models of count data that are available in the literature rule out the possibility of negative correlation. The other advantage of the model is its ease of implementation. Miravete claims that estimation is "fast and easy [...] in stark contrast to the existing literature on multivariate counts, which normally requires heavy numerical integrations."

He reports that "the estimates are generally robust across specifications," that there is evidence of unobserved heterogeneity, and that the distribution of actual plans is underdispersed whereas the distribution of effective (undominated) plans is overdispersed. In conclusion, "the results support the idea of strategic complementarity regardless of whether we consider the total or just the effective tariff options offered."

The evidence for the existence of strategic complementarities is very interesting and should be a spur to further research. There are many questions that remain to be answered. What is the source of the strategic complementarity and how can it be modeled? Is there data available that would allow the estimation of a "structural" model of competition? The dynamic dimension of competition should also be studied. Each of the markets is observed three times in this sample, so there is some information available on the evolution of competition in individual markets as well as across markets. The model underlying the estimation procedure is essentially static. What we are observing, however, is a repeated game in which strategic complementarity in the stage game does not necessarily translate into strategic complementarity in the dynamic game.

Clearly, we are very close to the beginning of serious empirical investigation of strategic complementarity. Miravete himself is a pioneer in this field. There are many important and exciting questions that remain to be addressed. The method introduced in this paper needs to be exploited more widely, but there is also a need to go beyond a descriptive approach.

***Marco Cipriani and Antonio Guarino,* "Herd Behavior in Financial Markets: An Experiment with Financial Market Professionals"**

The importance of informational efficiency in markets is well understood (Vives, 2008), but in recent years it has been challenged empirically and theoretically. One strand of this research addresses the phenomenon of herd behavior, in which investors imitate the behavior of other investors instead of using their private information to optimally forecast the market and invest accordingly. There are many empirical studies that attempt to analyze "herd behavior," but unfortunately they do not distinguish between truly imitative behavior ("following the herd") and the clustering that occurs when many individuals respond similarly to a public signal, for example. In fact, it is very difficult to study herd behavior using market-generated data because the information available to market participants is never directly observed. All the more reason to study herd behavior experimentally in a laboratory setting, as Cipriani and Guarino (2008) have done.

Models of herd behavior in financial markets are different from the models of herd behavior introduced by Banerjee (1992) and Bihkchandani, Hirshleifer and Welch (1992). As Avery and Zemsky (1998) point out, using a variant of the Glosten-Milgrom (1985) model, market prices aggregate publicly available information so informed investors can only profit by trading on the *difference* between their private information and the publicly available information. For this reason, an informed trader has an incentive to condition his trading strategy on his private information, thus revealing it, as long as his private valuation of the stock is different from the market price. Avery and Zemsky provide conditions under which an informational cascade (in which traders do not condition their trading strategy on their private information) cannot occur.

Informational cascades are a possibility if there is uncertainty about the occurrence of an information event, i.e., whether traders are informed or not. In that case, the market maker will update his beliefs less quickly than the informed traders and it may be the case that all traders, those with good signals and those with bad signals, have valuations that lie on the same side of the market price. In that case, all traders will want to trade in the same direction, either all buying or all selling, regardless of their private information.

Relatively little experimental research has been done on markets with uncertainty about informational events. Cipriani and Guarino develop an innovative design to investigate just such a setting. There are four main innovations in their paper. For the first time, they experimentally test a model in which informational herd behavior is theoretically possible. Previous studies (Cipriani and Guarino, 2005; Drehmann et al., 2005) use experimental designs based on models of markets in which informational herding is theoretically impossible. Secondly, they use professionals from the financial sector (traders, analysts, etc.), in place of the usual undergraduates, as subjects. Although the cost of attracting professional subjects limits the number of subjects, the use of professionals is important in validating the results of other studies that used only student subjects. The third innovation is their method of eliciting subjects' strategies. In the experimental market, subjects trade one after another and condition their trades on the history of trades and prices if they want. Instead of assigning each subject to a fixed point in the decision making sequence, as in the traditional herd model, in each period Cipriani and Guarino require every subject who has not yet traded to make a decision. Then one of the remaining subjects is selected at random to have his or her trade implemented. This method elicits more decisions than the standard method: if there are n subjects, the standard method elicits n decisions, whereas the Cipriani-Guarino method elicits $n!$ decisions. Finally, in addition to confirming the existence of herd behavior in situations where it should rationally occur, they find evidence of contrarian behavior, that is, subjects trading against the publicly revealed information, independently of the contrarian's private information, presumably because the contrarians suspected some irrationality on the part of the other traders. The paper's methodological and empirical innovations make a fascinating contribution to the literature on herd behavior.

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