Herd Behavior and Investment: Comment

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In an influential paper, David S. Scharfstein and Jeremy C. Stein (1990) modeled sequential investment by agents concerned about their reputation as good forecasters. Consider an agent who acts after observing the behavior of another ex-ante identical agent. Scharfstein and Stein argue that *reputational herding* requires that better agents have more *correlated* signals conditionally on the state of the world. They claim that without correlation the second agent would have no incentive to attempt to manipulate the market inference about ability by imitating the behavior of the first agent. In this note we show that in their model correlation is not necessary for herding, other than in degenerate cases.

Our clarification exploits a parallel with *statistical herding,* introduced by Abhijit V. Banerjee (1992) and Sushil Bikhchandani et al. (1992) (BHW). BHW feature investors who maximize expected profits in a common value environment and have access to conditionally *independent* private signals of bounded precision, while still observing the behavior of others. Eventually, the evidence accumulated from observing earlier decisions is sufficiently strong to swamp the private information of a single decision maker. Thereafter, everyone rationally copies the prevailing behavior.

We notice that payoffs have a common value nature in both the statistical and the reputational model. The observed behavior of other agents possibly affects the probability belief attached to different states of the world as well as the payoff conditional on each state. Herding arises from the interaction of these two channels affecting the expected payoff, be it physical or reputational. Positive differential conditional correlation of signals in the reputational model is tantamount to the introduction of positive payoff externalities in the statistical model. This reinforces the tendency to herd already present with independence.

The fact that differential conditional correlation is not needed for herding is a clear strength of the reputational herding model. It is not necessary to assume common unpredictable components of returns at the individual level in order to rationalize the empirical

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findings that individual prediction errors of security analysts are correlated.[1]

After setting up Scharfstein and Stein's model in Section I, we summarize their findings in Section II and provide a unified definition of herd behavior in Section III. Section IV contains our critique of their line of argument and clarifies the role of differential conditional correlation. In Section V we propose alternative robust scenarios where herding would indeed be driven by correlation. Section VI concludes.

I. Scharfstein and Stein's Model

Consider the following model of sequential investment by privately informed agents (managers), who are motivated by implicit incentives rather than the payoff of their principals (investors). Each agent is endowed with some private information (or signal) on the profitability of the investment (or state of the world) in a common value environment. More able agents have access to better information about the state in Blackwell's sense. The investment decision made by each agent on behalf of their principal is observed by two sets of receivers, who are possibly able to infer the agent's signal. First, other investors (agents and principals) who decide afterwards update their beliefs on the state. Second, the labor market assesses the ability of each agent on the basis of the choice made as well as the realized level of profits. As in Bengt R. Holmström's (1999) seminal model, agents are solely concerned about the market updating on ability performed on the basis on their observable decisions.

Specifically, Scharfstein and Stein look at the case with two agents who make individual investment decisions, one (agent B) after the other (A). The *state* of investment profitability is assumed to be binary, either high ($x_H > 0$) or low ($x_L < 0$), while not investing yields the safe return 0. Similarly, the *signal* is binary, either good (s_G) or bad (s_B). Each agent's *ability* type is again binary, either smart (S) or dumb (D). The prior beliefs, common to all agents and the labor market, are $\Pr(x_H) = \alpha$ and $\Pr(S^A) = \Pr(S^B) = \theta$, with superscripts referring to the agents. State and abilities are stochastically independent. Agents are assumed not to know their own type. While the signal received by smart agents is informative, with $\Pr(s_G|x_H, S) = p > q = \Pr(s_G|x_L, S)$, it is uninformative for dumb agents, i.e. $\Pr(s_G|x_H, D) = \Pr(s_G|x_L, D) = z$. Let $p(\theta) \equiv \Pr(s_G|x_H) = \theta p + (1-\theta)z$ and $q(\theta) \equiv \Pr(s_G|x_L) = \theta q + (1 - \theta)z$. The posterior beliefs $\mu_G \equiv \Pr(x_H|s_G)$ and $\mu_B \equiv \Pr(x_H|s_B)$ on the state are computed via Bayes' rule, e.g. $\mu_G = p(\theta)\alpha/[p(\theta)\alpha+q(\theta)(1-\alpha)]$. Notice that $\mu_G > \alpha > \mu_B$ by $p(\theta) > q(\theta)$.

[1]For recent empirical work cf. Owen A. Lamont (1995), Judith A. Chevalier and Glenn D. Ellison (1999), John R. Graham (1999), and Harrison G. Hong et al. (2000).

II. Scharfstein and Stein's Result

When is the first agent able to communicate her private information?[2] If the signals are transmitted credibly, the posterior beliefs on ability by the market are $\theta(s,x) \equiv \Pr(S|s,x)$ for $s \in \{s_B, s_G\}$ and $x \in \{x_L, x_H\}$, e.g. $\theta(s_G, x_H) = p\theta/[p\theta + z(1-\theta)]$ computed via Bayes' rule. There is a separating equilibrium where agent A in possession of signal s_G is believed to have such a signal when investing (and similarly an agent who does not invest is rightly believed to possess s_B) if

$$\mu_G\theta(s_G, x_H) + (1-\mu_G)\theta(s_G, x_L) \geq \mu_G\theta(s_B, x_H) + (1-\mu_G)\theta(s_B, x_L) \quad (1)$$

$$\mu_B\theta(s_B, x_H) + (1-\mu_B)\theta(s_B, x_L) \geq \mu_B\theta(s_G, x_H) + (1-\mu_B)\theta(s_G, x_L). \quad (2)$$

Substituting the posteriors on state and ability into (1) and (2), the incentive compatibility constraints for the first agent are:

$$\alpha[p-z][1-q(\theta)] \;\; \geq \;\; [1-\alpha][z-q][1-p(\theta)], \quad (3a)$$

$$\alpha[p-z]q(\theta) \;\; \leq \;\; [1-\alpha][z-q]p(\theta). \quad (3b)$$

In equation (4) at page 467 of their paper, Scharfstein and Stein make the additional assumption that the ex-ante distribution of signals is the same for smart and dumb agents,

$$z = \alpha p + (1-\alpha)q, \quad (4)$$

so that the actual signal received by the first agent does not contain any information about her own ability type. This non-informativeness condition is satisfied only for one particular prior belief α on the state. Whenever this condition is not satisfied, the agent acquires posterior information about own forecasting ability by merely observing the signal. Assuming non-informativeness has two important implications in their binary model.

First, a separating equilibrium exists for the first agent. Rewriting (4) as $\alpha[p-z] = (1-\alpha)[z-q]$, it is seen that both (3a) and (3b) hold if and only if $p(\theta) \geq q(\theta)$, already true by assumption. It follows that, in the most informative equilibrium, observation of A's investment decision allows subsequent agents to deduce her private information.

Second, if the signals were conditionally independent, there would also be a separating equilibrium for the second agent. Consider agent B who possesses signal s_G and moves

[2] When discussing the first agent A, we assume that the message sent by the second agent B does not influence the market's updating on A's ability. This is justified in any of three relevant scenarios: (i) if agent A is the only agent in the model, (ii) if the signals received by the two agents are conditionally independent, or (iii) if agent B is pooling in equlibrium. We are always in one of these scenarios in the cases discussed below.

after A has revealed s_B by choosing not to invest. Denote by $\theta(s_i, s_j, x_k)$ the posterior probability of B being of type S, conditionally on state x_k and on signals s_i and s_j being revealed respectively by agent A and B. In the case considered here,

$$\theta(s_B, s_G, x_H) = \frac{\Pr(s_G^B|S^B, s_B^A, x_H)\Pr(S^B)}{\Pr(s_G^B|S^B, s_B^A, x_H)\Pr(S^B) + \Pr(s_G^B|D^B, s_B^A, x_H)\Pr(D^B)}.$$

There is a separating equilibrium for the second agent B if

$$\begin{aligned} & \Pr(x_H|s_B, s_G)\theta(s_B, s_G, x_H) + [1 - \Pr(x_H|s_B, s_G)]\theta(s_B, s_G, x_L) \\ \geq\ & \Pr(x_H|s_B, s_G)\theta(s_B, s_B, x_H) + [1 - \Pr(x_H|s_B, s_G)]\theta(s_B, s_B, x_L). \end{aligned} \tag{5}$$

With conditionally independent signals, (5) is equivalent to $z \leq \alpha p + (1-\alpha)q$. This is seen by replacing α with the relevant prior μ_B in (3a). In the symmetric case, after agent A reveals s_G by investing, the condition for a separating equilibrium for B is $z \geq \alpha p + (1-\alpha)q$. Condition (4) is exactly necessary in order to have a separating equilibrium for the second agent in both cases.

Under the non-informativeness assumption (4), the left-hand side of (5) equals the right-hand side, as Scharfstein and Stein note on page 473. By assuming conditional dependence, i.e. $\Pr(s_G^B|S^B, s_B^A, x_H) < p$ and $\Pr(s_G^B|S^B, s_B^A, x_L) < q$, this indifference is broken. While a contradictory pair of signals still yields $\Pr(x_H|s_B, s_G) = \alpha$, the posterior reputations change as contradictory signals suggest that A and B are more likely to be dumb. Thus they write on page 468: "If the signals of smart managers are drawn independently from the distributions, our results concerning herd behavior fail to go through. Heuristically, herd behavior requires smart managers' prediction errors to be at least partially correlated with each other." Before demonstrating the fragility of this claim in Section IV, we provide a unified definition of herd behavior which can be applied to different models.

III. Herding Models

A. Models. Consider the following three models of sequential investment with common values. First, in the efficient benchmark with sequential information, each principal has direct access to some private information as well as to the information of previous principals. Second, in BHW's observational learning model, each principal again has access to private information, but can now observe only the investment decision of previous principals. Third, in Scharfstein and Stein's reputational model, the private information is held by agents concerned about their reputation rather than the payoffs to their principals. The investment decision is delegated to the agent by each principal, and previous investment decisions are again publicly observed.

In the reputational model, managerial investment decisions act as messages sent to the market. As in the cheap-talk model of Vincent P. Crawford and Joel Sobel (1982), such messages are per se costless to the agent. Nevertheless, different messages can be differently attractive to an agent (sender), depending on the information possessed. The market (receiver) can then re-assess ability on the basis of the message sent and the realization of the state. In this case, information can possibly be communicated in equilibrium. Since agents are indifferent about physical returns, investment decisions are arbitrarily associated with messages sent in equilibrium. In order to avoid this multiplicity problem, Scharfstein and Stein assume the association more favorable to the principal.

B. Herding. BHW's principals have direct access to private information when investing. Since the investment garbles the private signal, there is an informational inefficiency, compared with the benchmark model. When enough public information has been accumulated in the investment history, a boundedly informative private signal has no private value to the investor. The investor's decision is then determined only by public information, and does not depend on the private signal. Subsequent investors learn nothing from observation of such investment behavior, and herding results in the statistical model. This is referred to as *statistical herding,* since all later ex-ante identical individuals are in the same situation and take equally uninformative actions.

In Scharfstein and Stein's model, agency problems introduce further inefficiencies. The information is in the hands of agents, whose objectives are fundamentally different from those of the principals. Herding in the reputational model (*reputational herding*) arises when the investment made does not reflect any private information originally possessed by the agent. This happens when the most informative equilibrium is pooling, so that the ex-ante more profitable investment decision is taken regardless of the private information of the agent. This decision is also identical to that taken by the predecessor.

IV. Role of Correlation

As reported in Section II, Scharfstein and Stein find that differential conditional correlation is necessary for reputational herding. This result is valid in the binary model under condition (4), which restricts the prior belief on the state in such a way that the signal received by the first agent is not informative about her own ability. In subsection A we argue that such a non-informativeness condition does not have any clear role in the model. Once this non parsimonious assumption is lifted, reputational herding generally arises even in their binary model, without any need for conditionally correlated signals. The only advantage of correlation is to generate a stronger form of herding in this special model. In subsection B we compare the outcomes of different herding models. In subsection C we discuss the mechanics of herding and the role of correlation in these models.

A. Non-informativeness Condition. Our critique proceeds in four main steps: (i) In the binary model, the non-informativeness condition is sufficient but not necessary to guarantee the existence of a separating equilibrium for the first agent. (ii) When such condition is not imposed, herding by the second agent results even with independence in the binary model. (iii) The non-informativeness condition is a degenerate assumption, which holds only for a nongeneric prior on the state. It is necessarily not satisfied for the second agent, if it is satisfied for the first. (iv) Whenever the signal structure is nonbinary, inefficient reputational herding easily arises under the non-informativeness condition even in the absence of correlation. Thus, in more general models, the non-informativeness condition does not imply that correlation is necessary for herding.

First, we show that condition (4) is sufficient but not necessary to obtain a separating equilibrium for the *first* agent A.[3] Condition (3a) must fail if $p \leq z$, while (3b) fails if $z \leq q$; in either case there is no separating equilibrium for the first agent.[4] To rule out this uninteresting case, it is reasonable to assume $q < z < p$. There is an informative equilibrium for the agent when the prior on the state is not too extreme compared to the precision of the signal. For example, for symmetric signal distributions ($q = 1 - p$ and $z = 1/2$) we have $\theta(s_G, x_H) = \theta(s_B, x_L) > \theta(s_G, x_L) = \theta(s_B, x_H)$, so that (3a) and (3b) become $\mu_G \geq 1/2$ and $\mu_B \leq 1/2$, or equivalently $1 - p(\theta) \leq \alpha \leq p(\theta)$.[5] In this case, (4) restricts instead the prior belief on the state to be fair, $\alpha = 1/2$. There is room to depart from (4) and still get separation.

Second, in the binary model reputational herding obtains even with statistically independent signals whenever condition (4) is not satisfied. Then, one of the conditions (3a) and (3b) for separating equilibrium of the *second* agent fails. Therefore, when $z \neq \alpha p + (1 - \alpha) q$ — or equivalently for symmetric signal distributions unless the prior on the state is fair — the second agent herds with positive probability even with condition-

[3] Here, the non-informativeness condition guarantees the existence of an informative equilibrium for the first agent. More generally, even under this condition the equilibrium is not perfectly revealing when small misrepresentations of signals are possible, as in models with continuous signals.

[4] It is easy to check that under these same conditions there are no mixed-strategy informative equilibria.

[5] It can be easily shown that whenever there is a separating equilibrium there is also a mixed-strategy (or hybrid) equilibrium. For example, when $\alpha \in [1/2, p(\theta)]$ the agent with signal s_G invests with probability one, while the agent with signal s_B does not invest with probability $(2\alpha - 1)/(p(\theta) - 1 + \alpha) \in [0, 1)$ and invests with complementary probability. This equilibrium is clearly less informative than the separating equilibrium. There are no other mixed-strategy equilibria.

ally independent signals. The conditional dependence assumption, which Scharfstein and Stein claim necessary for reputational herding, is needed only in their knife-edge case. For instance, in the symmetric independent binary signal model with initial prior $\alpha \in (1/2, p]$, the second manager herds after the first manager credibly transmits a good signal by investing. If in addition $\alpha x_H + (1-\alpha) x_L < 0$, such herding is inefficient, i.e. it would not have resulted if the principal had direct access to the information. Furthermore, reputational herding arises with probability one with a sequence of agents endowed with conditionally independent signals, regardless of the initial prior.

Third, assuming that the signal is uninformative (by itself) about the agent's ability amounts to a restriction to a degenerate set of priors on the state. This is evident from equation (4) in the binary setting, and is clearly true with general information structures. Furthermore, the restriction has no clear conceptual role. Even in their model, the non-informativeness condition never holds for the second agent who decides after observing the (informative) decision of the first, as the relevant belief about the state cannot satisfy (4).

Fourth, we provide an example to illustrate that whenever the signal is not binary the non-informativeness condition (4) bears no connection with the indifference of the second agent mentioned above. The example also shows how excess reputational herding can arise even with conditionally independent signals. We add a third uninformative signal to the symmetric binary model, occurring with probability r. Then $\Pr(s_G|x, D) = \Pr(s_B|x, D) = (1-r)/2$ and $\Pr(s_N|x, D) = r$ for any $x \in \{x_H, x_L\}$. For type S, $\Pr(s_G|x_H, S) = \Pr(s_B|x_L, S) = (1-r)p$, $\Pr(s_B|x_H, S) = \Pr(s_G|x_L, S) = (1-r)(1-p)$, and $\Pr(s_N|x_H, S) = \Pr(s_N|x_L, S) = r$. Signals are conditionally independent and priors are $\alpha = \theta = 1/2$, so that the non-informativeness condition $\Pr(s|S) = \Pr(s|D)$ is satisfied. In an informative equilibrium agent A uses this strategy: message m_G is sent after signal s_G and with probability 1/2 after s_N, and m_B is sent otherwise. Consider agent B who acts after A sent m_G. Receipt of signals s_G or s_N will give B a posterior belief on state above 1/2, while signal s_B will drive this posterior below 1/2. In the potentially efficient strategy σ signals s_G and s_N are mapped into one message m_G, and s_B into m_B. Simple algebra proves that σ cannot be played in equilibrium, since the s_B type has a strict incentive to deviate to m_G. Similarly, truthtelling is not an equilibrium since s_B would deviate. Agent B is pooling in the most informative equilibrium if

$$\sqrt{(p+1/2)(1-p+1/2)} > 2r/\left(1-r\right). \tag{6}$$

Therefore, correlation is not needed for herding by the second agent. If the above condition does not hold, there is a partially separating equilibrium whereby s_G is mapped into m_G while s_N and s_B are mapped into m_B. Despite the non-informativeness condition, the incentive constraints for the second agent hold strictly, unless there is equality in (6). Furthermore, notice that agent B is behaving inefficiently, regardless of correlation.

B. Comparison of Outcomes. In general, investment decisions are determined by completely different incentives in the statistical and the reputational model. Nevertheless, their otherwise unrelated outcomes coincide in the special case with independent binary signals for appropriately defined physical payoffs (e.g. for $x_H + x_L = 0$ in the case of symmetric signals). Notice that there is no logical relation between statistical and reputational herding. For example, statistical herding results in the absence of reputational herding after the first agent invests under condition (4), conditional independence, and $\alpha x_H + (1-\alpha)x_L > 0$.[6] Conversely, reputational herding results without statistical herding after the first agent invests under condition (4), positive differential correlation, and $\alpha x_H + (1-\alpha)x_L < 0$.

Notice that when the information of the first decision maker is valuable (i.e. with $\mu_G x_H + (1-\mu_G)x_L \geq 0 \geq \mu_B x_H + (1-\mu_B)x_L$, assumption (7) of Scharfstein and Stein), the BHW outcome is efficient in the binary model with two decision makers. In this case, the action taken by the first decision maker fully reveals her information, so that the second individual has access to all the information socially available. Even if statistical herding arises, the outcome with two decision makers is efficient. Scharfstein and Stein maintained (4) and concluded that correlation of signals was an essential ingredient to obtain inefficient reputational herding. We have shown that this is not the case under independence in the binary signal model once condition (4) is lifted, as well as in more general models even under the non-informativeness condition (see the example at the end of subsection A).

C. Mechanics of Herding: Correlation as Externality. While the statistical model exogenously specifies identical payoff functions for all investors, payoffs in the reputational model are endogenously derived from the beliefs of the evaluator. Nevertheless, for given evaluator's beliefs about the agent's signaling strategy, reputational payoffs are again identical across decision makers. Payoffs have therefore a *common value* nature in both models. Notice that this analogy between the two models holds only for fixed evaluator beliefs. The strategic nature of reputational cheap talk adds the requirement that such beliefs be consistent in equilibrium with the signaling incentives of the agent.

It is useful to decompose the expected payoffs in both models in probabilities and

[6] Observe that the agency problem may actually improve information aggregation.

payoffs. In the BHW model, the payoff conditional on state remains fixed, independently of other investors' decisions. Their decisions only affect the probability belief about the state of the world, and therefore the relative attractiveness of investment.

In the reputational model, consider the second agent's expected reputational payoff given by equation (5). On the one hand, the signal revealed by the first agent and that possessed by the second affect the *probability* assessment of the state of the world. On the other hand, the *conditional reputational payoff* corresponding to the updated belief about an agent's ability depends on the investment made (or message reported) by both agents as well as the realized state of the world. When the agents have conditionally independent signals, this second channel is inactive, because the signals inferred from the behavior of other agents do not *directly* affect the conditional reputational payoffs $\theta(s_B, s_G, x_k) = \theta(s_G, s_G, x_k) = \theta(s_G, x_k)$. In this case, conditional payoffs change only insofar as the different probability assessment on the state drives the evaluator to change beliefs about the agent's signaling strategy.

In both the BHW model and the reputational model with conditional independence, information about the state accumulates by observing the behavior of the previous investors. Thus, the probability weights on some of the conditional payoffs increase. In the two-signal model, the issue is whether the evaluator expects separation. As long as the evaluator maintains such beliefs, the agents have common values. Eventually, the agent prefers to deviate by pretending to have the ex-ante more likely signal. The most informative equilibrium is then pooling. The mechanics of the binary-signal reputational model is exactly the same as that of the statistical model. Differential correlation of the signals introduces an externality in the reputational payoff, not present in the basic BHW model. With positive differential correlation there is an additional incentive to herd through the payoff channel, equivalently to the introduction of positive payoff externalities in the statistical model. The BHW-like probability channel and the payoff channel are then necessarily intertwined in determining whether the most informative equilibrium is pooling.

Notice that informative signals are correlated with the state, even when they are conditionally independent. Furthermore, signals of more informed agents are more correlated with the state, so that the probability that the second agent is smart increases conditionally on receiving the same signal as the first agent. With more general signal structures, the evaluator's belief as well as the conditional payoffs change with the prior on the state, even while sustaining a non-pooling equilibrium. The endogeneity of the evaluator beliefs introduces an indirect dependence of the reputational payoff on the information revealed by previous agents. In general, the probability and the payoff channels necessarily interact even with independent signals.

V. When is Correlation Necessary for Herding?

Adapting BHW's logic to the reputational setting of Scharfstein and Stein, we have seen that reputational herding occurs even without correlated prediction errors. This section investigates situations where differential conditional correlation is indeed necessary to obtain herding in a reputational environment. We outline three scenarios: (A) In an investment model with pure private values, only conditional correlation can force later agents to condition their behavior on the predecessors' actions. (B) In a model where agents have intermediate levels of private information about their own ability, correlation is necessary and sufficient to generate herding. (C) With unbounded private information precision on the state of the world, correlation is necessary for herding and it also suffices when the information is of sufficiently bounded precision on own ability.

A. Private Value Model. In the reputational setting with differential conditional correlation, existence of informative equilibria depends on the interplay of the probability and the payoff channel. It is impossible to isolate one channel from the other, unless no information about the state can be inferred from observation of the message sent by previous agents.

Consider instead an environment with completely idiosyncratic investment opportunities. Modify the Scharfstein and Stein model by allowing for agent-specific independent states of the world, x^A and x^B. Agent i receives a signal s^i which carries information about x^i but not about x^j, for $i, j \in \{A, B\}$. Without differential conditional correlation, the information and thus the decision of agent A is without relevance for the decision problem of agent B. In this pure private-value environment, observation of the investment made by others does not convey any information on one's own state. Therefore, agents act independently on their own information, and there are no herding effects. However, with differential conditional correlation of signals, the signal of agent A is relevant for the interpretation of agent B's information. If the signals agree, the likelihood that B is smart is larger, and conversely when signals are contradictory.

With the probability channel mute, payoff externalities from differentially conditionally correlated signals are necessary to have reputational herding effects. Nevertheless, this assumption is not particularly appealing in this case. It is not clear why there should be any particular correlation structure in the signals for otherwise unrelated decision problems.

B. Partial Private Knowledge on Own Ability. As illustrated by Brett Trueman (1994), agents who possess prior private information on own ability have an incentive to differentiate themselves. With (sufficiently) accurate knowledge about ability, there is an informative equilibrium for any prior on the state of the one-period model. This is easily seen by modifying the basic single-agent game (with $q = 1 - p$ and $z = 1/2$) to allow for perfect private knowledge of own ability. In this case there exists for all $\alpha \in [0, 1]$ an informative equilibrium whereby the smart type reveals truthfully her signal, while the dumb type pools with one of the messages sent by the smart type. When $\alpha \geq 1/2$, the dumb type with signal s_G sends message m_G, while that with s_B randomizes by announcing m_G with probability $\nu \in [0, 1)$ and m_B with remaining probability $1 - \nu$. The probability ν is determined by the indifference of the dumb type with signal s_B,

$$\alpha\theta\left(m_B, x_H\right) + (1-\alpha)\theta\left(m_B, x_L\right) = \alpha\theta\left(m_G, x_H\right) + (1-\alpha)\theta\left(m_G, x_L\right). \qquad (7)$$

If $\nu = 1$ then $\theta\left(m_B, x_H\right) = \theta\left(m_B, x_L\right) = 1$, and the left-hand side of (7) strictly exceeds the right-hand side. If $\nu = 0$ then $\theta\left(m_B, x_H\right) = \theta\left(m_G, x_L\right) < \theta\left(m_B, x_L\right) = \theta\left(m_G, x_H\right)$ and the right-hand side weakly exceeds the left-hand side. By continuity some $\nu \in [0, 1)$ gives the required indifference. Symmetrically, when $\alpha \leq 1/2$ there is an informative equilibrium where the dumb type announces m_B when receiving s_B and randomizes between m_B and m_G when receiving s_G. Thus, herding cannot obtain when agents have perfect knowledge of their own ability and signals are conditionally independent.[7]

Trueman's result extends to the case of conditionally dependent signals and partial knowledge of own forecasting ability, as exemplified by Christopher N. Avery and Chevalier (1999). When smart agents have perfectly correlated signals, pooling is the most informative equilibrium for the second agent if and only if the information about own ability type is sufficiently imprecise. We show below that correlation is necessary and sufficient to generate herding for an intermediate range of knowledge about own type.

Consider Scharfstein and Stein's model with $q = 1 - p$ and $z = \alpha = 1/2$ and where smart agents have perfectly correlated signals. Agents receive an additional conditionally independent signal about own ability. This signal is promising with probability γ, and otherwise unpromising. A promising agent is smart with probability θ_P, an unpromising with probability θ_U. Necessarily the prior reputation satisfies $\theta = \gamma\theta_P + (1 - \gamma)\theta_U$.

Since the model is symmetric, there is a separating equilibrium for agent A where investment takes place only after observation of signal s_G. The probability that agent B is smart conditionally on being promising and receiving a signal which disagrees with A's is $\theta_P(1 - \theta)/(1 - \theta\,\theta_P)$, as derived by Avery and Chevalier. This is the expected posterior reputation for B who successfully communicates to be promising and in possession of a

[7] Complete learning would not result if instead principals had direct access to the information of their agents.

signal opposite to A's. The most informative equilibrium for B is pooling if and only if this reputation falls short of the prior reputation θ, i.e. if and only if $\theta_P < \theta_P^* \equiv \theta/[1-\theta(1-\theta)]$. Otherwise the most informative equilibrium is of the Trueman signaling kind. When instead agents have conditionally independent signals, similar calculations show that pooling by B obtains if and only if $\theta_P < \theta_P^{**} \equiv \theta/[1-\theta(1-\theta)(1-4p(1-p))]$. Clearly, $\theta_P^{**} < \theta_P^*$, so whenever $\theta_P \in (\theta_P^{**}, \theta_P^*)$, there exists a separating equilibrium for B when signals are conditionally independent, and there is no separating equilibrium for B when signals are correlated. Hence in this case correlation is required for herding.

Interestingly, neither equilibrium is efficient. In the pooling equilibrium, there is too little tendency to use own information. In the signaling equilibrium some unpromising agents contradict their predecessor inefficiently, so there is "anti-herding".

C. Unbounded Informativeness on State. What happens in a dynamic model with more than two agents? Lones Smith and Sørensen (2000) point out that unbounded signal strength on the state precludes herding à la BHW, as no uncertain prior then suffices to overwhelm all possible private signals. We now present a four-signal example with unbounded precision on the state. Correlation is then necessary and sufficient to generate herding if signals are of sufficiently bounded informativeness on own ability.

The signal distribution for type T is $\Pr(s_1|x_H,T) = \Pr(s_4|x_L,T) = r_T$, $\Pr(s_2|x_H,T) = \Pr(s_3|x_L,T) = q(1-r_T)$, $\Pr(s_3|x_H,T) = \Pr(s_2|x_L,T) = (1-q)(1-r_T)$, $\Pr(s_4|x_H,S) = \Pr(s_1|x_L,S) = 0$. We assume that $q \in (1/2,1)$ and $0 \le r_D < r_S \le 1$. Note that s_1 perfectly reveals state x_H while similarly s_4 reveals x_L. Prior is $\alpha = 1/2$, while $\theta^I \in (0,1)$ can vary across agents. For the first agent A there is an informative equilibrium where message m_G is sent upon observation of signals s_1 or s_2, and message m_B after s_3 or s_4.

Assume first that the signals are conditionally independent and restrict attention to the situation after A had sent message m_G credibly. Receipt of signals s_1, s_2, or s_3 gives B a posterior belief in state x_H above 1/2, while signal s_4 drives the posterior to 0. The strategy σ whereby signals s_1, s_2, s_3 are mapped into one message m_G while s_4 is mapped into m_B is an equilibrium for the second agent B. This reasoning can be applied iteratively to show that any agent will use strategy σ as long as only m_G has been reported by the predecessors. This is an informative equilibrium, because along a pure m_G history the posterior on the state monotonically increases to 1, while if m_B is reported by someone, the posterior will be revised to 0. In any case, there is complete long-run learning on the state of the world.

Finally, consider the case with conditionally dependent signals. For simplicity, assume as above that the signals of agents A and B are perfectly correlated when they are both smart. Again, concentrate on the situation after A reported m_G. Simple algebra shows that the separating strategy σ from above is not incentive compatible for B when

$$(1 - r_S)\theta^A > (1 - r_D)(\frac{r_S}{r_D} - 1)(1 - \theta^A) \tag{8}$$

Under (8), only herding is an equilibrium. Clearly, as more agents are added in this setting, herding results *only* from correlation without need for additional conditions like (4). Condition (8) is easily satisfied by the parameters. It is more likely to hold when A has a better reputation, and when there is only a small difference in ability between types S and D. These conditions are conducive to herding by the second agent B, who has little to gain by contradicting A's report.

VI. Conclusion

Agency-driven herding results with greater generality than realized by Scharfstein and Stein when formulating their innovative model. Reputationally concerned agents herd, unless they know enough a priori about their own information quality. Differential conditional correlation adds to the tendency to herd, but it is not required in a number of natural models. When instead agents have substantial prior private information on their forecasting ability, herding requires the "sharing-the-blame" effect introduced by Scharfstein and Stein.

Our approach exploits the evident similarity of reputational and statistical herding models. In either setting, consideration of conditionally dependent signals and payoff externalities complicates tremendously the analysis of the multi-agent dynamic model. With differential conditional correlation, the dynamic model cannot be solved forward, other than in the case where the second agent always herds. If this agent's behavior were informative, it would also be necessary to go backward and check the behavior of the first agent. For this reason, only very special reputational models have been studied to date. The dynamic model with conditionally independent signals can instead be manageably solved forward. Its outcomes depend on the building-block model with a single agent. A general analysis of this static model of reputational cheap talk is needed.

The empirical interest on the topic also calls for more fundamental work in the area. In both the statistical and reputational model, observational learning from others results in outcomes less drastic than herding. Typically, individual behavior does not incorporate all private information available. For the purpose of empirical work, it is useful to understand the biases and information losses which can be attributed to the agency problem.

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