Information Cascades and Observational Learning

Sushil Bikhchandani, David Hirshleifer, and Ivo Welch

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Information cascades and observational learning

An *information cascade* is a situation in which an individual makes a decision based on observation of others without regard to his own private information.

Social observers have long recognized that human beings have a deep-rooted proclivity to imitate. According to Machiavelli, "Men nearly always follow the tracks made by others and proceed in their affairs by imitation." Even animals imitate in choices of mate and territories. A common view among social scientists equated the conformity of individuals in large groups with irrationality—"fads," "mass psychology," or the "madness of crowds."

However, there has also been recent recognition of the benefits of social influence. For example, zoologists have argued that despite its possible disadvantages, imitation is an evolutionary adaptation that has promoted survival over thousands of generations by allowing individuals to take advantage of the hard-won knowledge of others (Gibson and Hoglund 1992).

Nevertheless, as this entry discusses, even when individuals are entirely rational, observational influence helps surprisingly little, leading to social outcomes that are inefficient, and which superficially may seem irrational. Irrationality undoubtedly affects social behavior. However, recent developments in the theory of observational learning give reason to be skeptical about casual attributions of perverse social outcomes to irrational passions.

Why do people tend to "herd" on similar actions? Why is mass behavior prone to error and fads? The theory of observational learning helps explain some otherwise puzzling phenomena about human behavior and offers a vantage point for issues in economics and business strategy

We will call influence resulting from rational processing of information gained by observing others *observational learning* or *social learning*. Observational learning is only one of several possible causes of convergent behavior. The simplest reason is that individuals can have identical beliefs and decision problems. Alternative reasons for conformity include positive payoff externalities, which lead to conventions such as driving on the right hand side of the road; preference interactions, as with everyone desiring to wear the more "fashionable" clothing as determined by what others are wearing; and sanctions upon deviants, as with a dictator punishing opposition behavior.

However, among these theories, only observational learning explains why mass behavior is error prone, idiosyncratic, and often fragile in the sense that small shocks might lead to large shifts in behavior. To understand how these effects arise, consider a sequence of rational individuals who take identical decisions under uncertainty. Each individual makes use of all relevant information – his own private signal and any inferences drawn from observing the choices of preceding individuals. As soon as the information gleaned from publicly observable choices of others is even slightly more informative than the individual's private signal, he imitates his immediate predecessor without regard to his private information. Therefore, this individual's choice is uninformative about his signal and at that point, an information cascade starts. His immediate successor finds herself in an identical position; she imitates him (her immediate predecessor) and ignores her private signal. Based on the information conveyed by the actions of the first few individuals – the ones not in a cascade – every succeeding individual takes the same action. This action may be an incorrect one, so even small shocks such as the possible arrival of a different type of individual or a little new information can overturn it. Thus, observational learning explains not only conformity, but also rapid and short-lived fluctuations such as fads, fashions, booms, and crashes.

The social outcome is highly error-prone because there is an information externality. If an individual selects an action that depends on his information signal, his action provides useful information to later decision-makers. However, it is in the self-interest of an individual in a cascade to ignore his signal; therefore later individuals do not get the benefit of learning his private signal. Thus, the failure of individuals to take into account the welfare of later decision-makers leads to inefficient information aggregation.

This entry focuses on the situation where individuals with diverse private information learn by observing the actions of others or the consequences of these actions.[1]

A Model of Observational Learning

Observable Actions versus Observable Signals

Consider a setting in which individuals choose an action in a chronological order. Each individual starts with some private information, obtains some information from predecessors, and then decides on a particular action. We consider two scenarios. In the *observable actions* scenario, individuals can observe the actions but not the signals (i.e., private information) of their predecessors. As demonstrated below, cascades will arise in this model. We compare this to a benchmark *observable signals* scenario in which individuals can observe both the actions and signals of predecessors.[2]

The main ideas are seen in the following simple example. Several risk neutral individuals decide in sequence whether to *adopt* or *reject* a possible action. The payoff to adopting, V, is either 1 or –1 with equal probability; the payoff to rejecting is 0. In the absence of further information, both alternatives are equally desirable. The order in which individuals decide is given and known to all.

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[1] Previous surveys of this literature include Bikhchandani, Hirshleifer, and Welch (1998) and Chamley (2004).

[2] See Welch (1992), Bikhchandani, Hirshleifer, and Welch (1992), and Banerjee (1992).

Each individual's signal is either High (H) or Low (L). It is H with probability $p > ½$ if $V = 1$, and with probability $1–p$ if $V = –1$. Bayes' rule implies that after observing one H, an individual's posterior probability that $V = 1$ is p; if instead one L is observed the probability that $V = 1$ is $1–p$. All private signals are identically distributed and independent conditional on V. Naturally, an individual's posterior belief about V also depends on information derived from predecessors. All this is common knowledge among the individuals.

In the observable signals scenario, each individual observes predecessors' information signals. As the pool of public information keeps increasing, later individuals will settle on the correct choice (adopt if $V = 1$, reject if $V = –1$) and thus behave alike.

Because actions reflect information, it is tempting to infer that if only the actions of predecessors are observable, the public information set will also gradually improve until the true value is revealed almost perfectly. However, that is not the case. In the observable actions case, individuals often converge fixedly on the same wrong action – that is, the choice that yields a lower payoff, ex post. Furthermore, behavior is *idiosyncratic* in that the choices of a few early individuals determine the choices of all successors.

Returning to our example, the first individual, Asterix, adopts if his signal is H and rejects if it is L. All successors can infer Asterix's signal perfectly from his decision. If Asterix adopted, then Beatrix, the second individual, should also adopt if her private signal is H; as Beatrix sees it, there have now been two H signals, the one she inferred from Asterix's actions and the one she observed privately. However, if Beatrix's private signal is L, it exactly offsets Asterix's signal H. She is indifferent between adopting and rejecting. We assume, for expositional simplicity, that as Beatrix is indifferent between the two alternatives, she tosses a coin to decide. (By similar reasoning, if Asterix rejected, then Beatrix should reject if she observes L, and toss a coin if her signal is H.)

The third individual, Cade, faces one of three possible situations: both predecessors adopted (AA), both rejected (RR), or one adopted and the other rejected (AR or RA). In case AA, Cade also adopts. He knows that Asterix observed H and that more likely than not Beatrix observed H too (although she may have seen L and flipped a coin). Thus, even if Cade sees a signal L, he adopts. Consequently, Cade's decision to adopt provides no information to his successors about the desirability of adopting. Cade is therefore in an *information cascade*; his optimal action does not depend on his private information. The uninformativeness of Cade's action means that no further information accumulates. Everyone after Cade faces the same decision and also adopts based only on the observed actions of Asterix and Beatrix. By similar reasoning, RR leads to a cascade of rejection starting with Cade.

In the remaining case where Asterix adopted and Beatrix rejected (or vice versa), Cade knows that Asterix observed H and Beatrix observed L (or vice versa). Thus, Cade's belief based on the actions of the first two individuals is that the $V = 1$ and $V = -1$ are equally likely. He finds himself in a situation identical to that of Asterix, so Cade's decision is based only on his private signal. Then, the decision problem of the fourth individual, Daisy, is the same as Beatrix's. Asterix's and Beatrix's actions have offset and thus carry no information to Eeyore. And if Cade and Daisy both take the same action – say, adopt – then an adoption cascade starts with Eeyore.

An individual's optimal decision rule is as follows. Let d be the difference between the number of predecessors who adopted and the number who rejected. If $d > 1$, then adopt regardless of private signal. If $d = 1$, then adopt if private signal is H and toss a coin if signal is L. If $d = 0$, then follow private signal. The decisions for $d = -1$ and $d < -1$ are symmetric. The difference between adoptions over rejections evolves randomly, and very quickly hits either the upper barrier of +2 and triggers an adoption cascade, or the lower barrier of –2 to trigger a rejection cascade. With virtual certainty, all but the first few individuals end up doing the same thing.

Order of Information, Noise, and Information Externalities

The reason the outcome with observable actions is so different from the observable signals benchmark is that once a cascade starts, public information stops accumulating. An early preponderance towards adoption or rejection causes all subsequent individuals to ignore their private signals, which thus never join the public pool of knowledge. Nor does the public pool of knowledge have to be very informative to cause individuals to disregard their private signals. As soon as the public pool becomes slightly more informative than the signal of a single individual, individuals defer to the actions of predecessors and a cascade begins.

Furthermore, the type of cascade depends not just on how many H and L signals arrive, but the order in which they arrive. For example, if signals arrive in the order HHLL..., then all individuals adopt, because Cade begins an adoption cascade. If, instead, the same set of signals arrive in the order LLHH..., all individuals reject, as Cade begins a rejection cascade. Thus, in the observable actions scenario, whether individuals on the whole adopt or reject is *path dependent*.

A cascade is likely even when private signals are noisy. Specifically, in the above example, let the probability that the signal is correct be $p = 0.51$. The probability that an adoption or rejection cascade forms after the first two individuals is close to 75 percent![3] After eight

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[3] The signal sequences HH (i.e., Asterix observes H and Beatrix observes H) and LL cause adoption and rejection cascades respectively (starting with Cade). Similarly, HL and LH each lead to adoption and rejection cascades with probability 0.5 each (if the action chosen by Beatrix after a coin flip is the same as Asterix's). The sum of the probabilities of these events is about 0.75.

players the probability is only a 0.004 that the individuals are not in a cascade.[4]

Although a cascade starts eventually with probability one, the probability of being in a correct cascade (i.e., an adoption cascade when $V = 1$ and a rejection cascade when $V = -1$) is only 0.5133.[5] If individuals do not observe their predecessors' choices (or information) then they would choose an action based only on the private signal; the probability that an individual's choice is correct is 0.51. Thus, the increase in accuracy from observing the actions of predecessors is small. Contrast this with the observable signals scenario, where after many individuals the publicly observed information signals of predecessors are virtually conclusive as to the right action.

More generally, even when individuals have more accurate signals (p is much greater than 0.5), the information contained in a cascade is substantially short of efficient information aggregation. Consider the benchmark observable signals scenario. Individuals far enough out would know the true state almost perfectly. The correctness of these individuals' actions increases from p to 1 due to information revelation. Figure 1 graphs, as a function of the signal accuracy p, the fraction of potential accuracy improvement realized in the observable actions scenario.[6] This fraction increases from 0 for very noisy signals to 0.50 for very informative signals. Thus, in the basic model, at most half of the potential gains are realized.

<figure 1 here>

An individual's private information is useful to others. However, in choosing the optimal action, the individual ignores this benefit: with the onset of a cascade in the observable actions scenario, individuals rationally take uninformative imitative actions. This information externality reduces information aggregation. To see this, consider an alternative benchmark scenario in which (i) each individual maximizes a discounted sum of payoffs to all individuals and (ii) no individual can directly reveal his private information; others learn of his information only through this individual's choice of action. The onset of cascades in this scenario is delayed (compared to the observational actions scenario); information aggregation is efficient subject to the constraint that private information is revealed only through actions.

Fragility

Of course, in reality we do not expect a cascade to last forever. The arrival of better informed individuals or the release of new public information can easily dislodge a cascade.

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[4] This is the probability $|d| < 2$ for each of individuals 3 through 8.

[5] The calculation can be found in Bikhchandani, Hirshleifer, and Welch (1992).

[6] The fraction of potential accuracy improvement realized is $(Pr[\text{correct cascade}]-p)(1-p)$. From (3) in Bikhchandani, Hirshleifer, and Welch (1992), $Pr[\text{correct cascade}] = p(p+1)/2(1-p+p^2)$.

Indeed, participants in a cascade know that the cascade is based on information that is only slightly more accurate than the private information of an individual. Thus, a key prediction of the theory is that behavior in cascades is *fragile* with respect to small shocks.[7]

How robust are the conclusions that cascades are born quickly and idiosyncratically, and shatter easily? When some assumptions in the example are relaxed, is the aggregation of information still inefficient or delayed?

Robustness of basic model

The conclusions of the basic model remain robust along a number of dimensions. We discuss here alternative assumptions about the action space and the signal, which affect the conclusions to some extent.

The action space: In the basic model, players make inferences about others' signals from observed choices. When there are many possible actions, the action choice can convey more information. If the set of actions is continuous and unbounded,[8] then actions fully reveal players' information and cascades do not arise (Lee 1993). However, if players are even slightly unsure of the payoff functions of other players then there is a discontinuous shift to a slower learning process in which information aggregation is inefficient (Vives 1993). In many real-world settings, the action space is bounded or partly discrete: investment projects that have a minimum efficient scale, elections amongst a discrete set of alternatives, a car purchase of a Ford or a Toyota, a takeover decision of whether to bid or not bid for a target firm, and a decision to hire or fire a worker.

The signal space: As in the simple two signal example presented above, in settings with a large but discrete set of signal values cascades occur with probability close to one and are sometimes incorrect. In some continuous signal settings cascades do not form (Smith and Sorensen 2000), but an informational externality remains and information aggregation is inefficient. Furthermore, with substantial probability individuals soon follow the behavior of recent predecessors and with some probability that action is incorrect. Indeed, with any finite number of individuals, a continuous signal setting is observationally similar to a discrete signal setting that approximates the continuous model. In other words, in a continuous signals setting, herds tend to form in which an individual follows the behavior of his predecessor with high probability, even though

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[7] There are some models enforced by the threat of sanctions upon defectors in which rare shifts occur when the system crosses a critical value that shifts the outcome from one equilibrium to another (Kuran 1989).

[8] If the action space is a continuous but bounded interval, then when an individual optimally chooses one of the endpoints of the interval, the value of his signal is not revealed by his action. In consequence, incorrect cascades can form at the end points of the interval. For example, if a set of firms cannot invest less than zero, they may incorrectly cascade on zero investment.

this action is not necessarily correct. Thus, the welfare inefficiencies of the discrete cascades model are also present in continuous settings (Chamley 2004, ch. 4).

Observability of payoffs or signals: Several papers consider the inefficiency of social learning when there is some degree of observability of payoffs (Caplin and Leahy 1994). Furthermore, even if individuals can observe the payoffs of predecessors, inefficient cascades can form and with positively probability last forever, because a cascade can lock into an inferior choice before sufficient trials have been performed on the other alternative to persuade later individuals that this alternative is superior (Cao and Hirshleifer 2002). Indeed, if individuals can observe a subset of past signals, such as the past *k* signals, inefficient cascades can form.

Other assumptions of basic model: When individuals have the freedom to delay their action choice, in equilibrium there is delay, followed by a sudden onset of cascades when an individual commits to an action (Chamley and Gale 1994, Zhang 1997). The existence, idiosyncrasy and fragility of cascades are robust to relaxing other assumptions as well, including allowing for differing information precision, costly information acquisition, and heterogeneous observable tastes (see Bikhchandani, Hirshleifer, and Welch 1998 and the references therein). Inefficient cascades still form when individuals have reputational as well as informational motives to herd (Ottaviani and Sorensen 2000). When individuals are imperfectly rational, inefficient cascades still form, but overconfident individuals provide social value when their impetuous choices shatter incorrect cascades (Bernardo and Welch 2001).

APPLICATIONS:

There has been extensive testing of information cascades models in the laboratory (see CASCADES EXPERIMENTS entry). Experiments provide some support for information cascades and observational learning (Anderson and Holt 2000).

DEMAND FOR GOODS AND SECURITIES: The information cascades theory implies that consumer purchase decisions will be influenced by others, as occurs, for example, in automobile purchases in Finland (Grinblatt, Ikäheimo and Keloharju 2005). Incorrect cascades arise in settings in which individuals observe summary statistics of others' behavior, such as whether one product is outselling another. Golder and Tellis (2004) provides evidence that information cascades play a role in the dynamics of product life cycles. The cascades theory also implies that individuals who are viewed by others as being better informed will be fashion leaders, in the sense that their decisions can trigger immediate cascades. This can explain the effectiveness of a star basketball player's endorsement of a brand of sneakers, but not of his endorsement of a brand of beer.

Even without fashion leaders, there are ways for individuals to have disproportionate effects on the onset of information cascades. In a salient 1995 episode, management gurus Michael Treacy and Fred Wiersema secretly purchased 50,000 copies of their business strategy book in order to inflate the sales measured used to construct the *New York Times* bestseller list. Despite mediocre reviews, their book not only made the bestseller list, but subsequently, sold well enough to continue as a bestseller without further demand intervention by the authors.

The cascade theory explains why the ubiquitous and legitimate marketing method of offering a low initial price may be a successful scheme for introducing an experience good: early adoptions induced by the low price help start a positive cascade. This idea was first analyzed by Welch (1992) to explain why initial public offerings of equity are on average severely underpriced by issuing firms. Indeed, a seller may be tempted to cut price secretly for early buyers, so that later buyers will attribute the popularity of the product to high quality rather than low price.

MEDICAL: Most doctors cannot stay fully abreast of relevant medical advances in their areas. An observational learning perspective implies that medical treatments will be characterized by localized conformity and occasional reversals of this conformity. It has indeed been claimed that a blind reliance by physicians upon their colleagues' medical decisions commonly leads to surgical fads and even to treatment-caused illnesses (Robin, 1984; Taylor, 1979). Many dubious practices seem to have been adopted initially based on weak information (elective hysterectomy, ileal bypass, and tonsillectomy), and then later abandoned. A few decades ago, differences in tonsillectomy frequencies in different countries and regions were extreme.

POLITICS: People learn about others' political beliefs by observing how they vote and from opinion and exit polls. Several studies of political momentum show that early respondents carry disproportionate weight (see Bartels 1988). Iowa voters gave an obscure candidate named Jimmy Carter a conspicuous early success in the 1976 U.S. presidential campaign. Many southern states have coordinated their primaries early in the election cycle on the same date ("Super Tuesday"), in order to increase their influence on the presidential election. The expanding turnout of protestors in Leipzig in 1989, which triggered the fall of communism in East Germany, has been modeled as an information cascade (Lohmann 1994).

CRIME: The decision to commit crime is influenced by observing the behavior of others (see Kahan 1997). When an individual observes that peers are committing a crime, he may infer that they perceive the probability of gain to be high and of punishment or stigmatization to be low. Sometimes public news of one kind of crime leads to more of that crime, as with tax evasion (Sheffrin and Triest 1992), and more spectacular crimes such as assassinations, hijackings, kidnappings, and serial murders (Bandura 1973; Berkowitz 1973, Landes 1978). Other studies have found that crime is tied to whether others in the neighborhood are committing crime, even after controlling for demographic variables and law enforcement (see Glaeser, Sacerdote, and Scheinkman 1996, Skogan 1990).

FINANCE: The decision of individual investors to participate in the stock market and the buying and selling decisions of mutual fund managers are influenced by their peers' decisions (Hong, Kubik and Stein 2005, Brown et al 2005), and there is some indication that herding by mutual funds influences prices (Wermers 1999). The rise in popularity of investment clubs and of day-trading in the 1990s was probably due in part to a self-feeding effect in which individuals learned from the media or word of mouth that many others were day trading. Several theoretical models of securities market trading have been developed which embody either cascade- or cascade-like features (Avery and Zemsky 1998, Lee 1998, Cipriano and Guarino 2003). Devenow and Welch (1996), Bikhchandani and Sharma (IMF 2000), and Hirshleifer and Teoh (2003) review the theory and evidence of social learning in finance.

ZOOLOGY: Zoologists have documented observational learning, and proposed that information cascades are exhibited in a variety of animal behaviors, including “false alarm” flights from possible predators, selection of night roosts by birds, and mate choice copying in various animal species (Giraldeau et al 2002).

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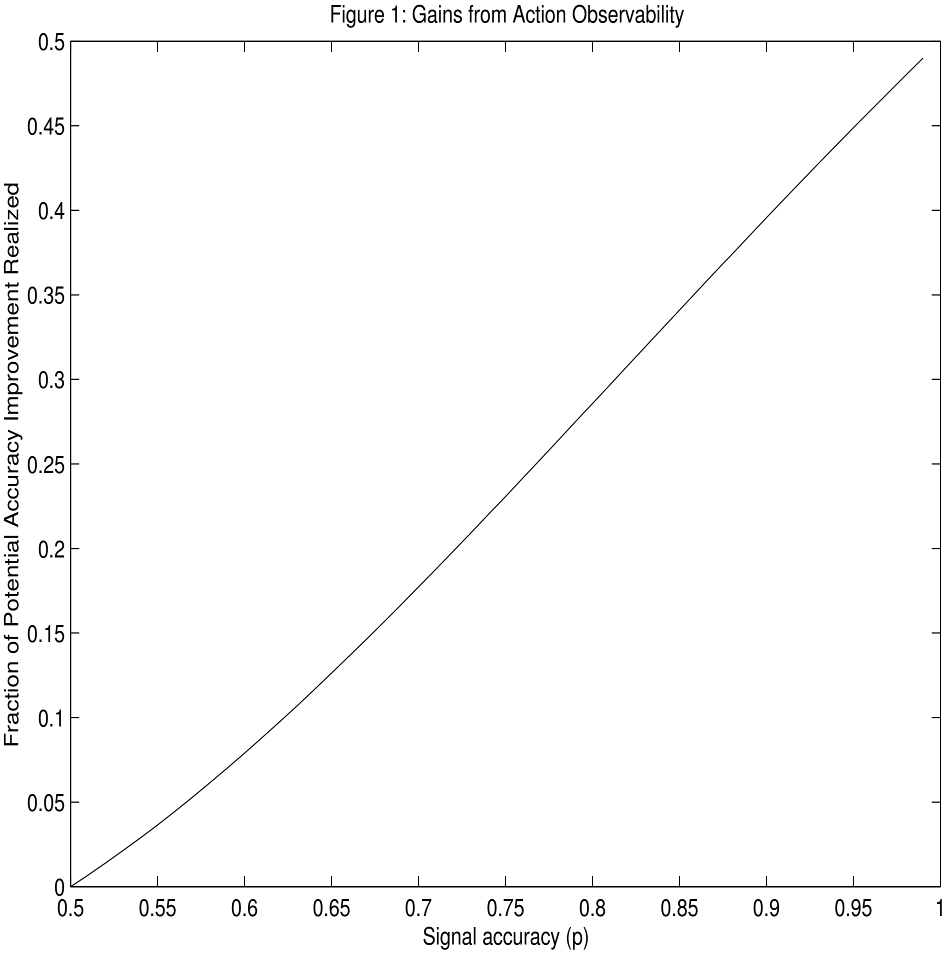

Figure 1: Fraction of potential accuracy improvement realized $\left([\frac{p(p+1)}{2(1-p+p^2)} - p]/(1-p)\right)$ as a function of signal accuracy (p is the probability that the signal is high given that the true value is high).