



Delay in social learning[★]

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ABSTRACT

We study a class of social learning games in which players choose whether and when to make an irreversible investment. We ask whether the option value of learning induces delay. Surprisingly, under natural and standard assumptions, delay does not arise in equilibrium. Although waiting even momentarily would yield informative observations, we show that this learning is payoff-irrelevant. As a result, players either invest immediately or not at all.

Lab rat 1: “Did you get the COVID vaccine yet?”

Lab rat 2: “Nah, I’m waiting for the results of the human trials.”

1. Introduction

Social learning from others’ experiences is an important source of information when trying a new product or investing into R&D. The option value of social learning can induce delay, with 31% of the public saying they want to “wait and see” how others react to the COVID-19 vaccine before getting it themselves (Hamel et al., 2021), and oil companies strategically delaying drilling and development by years to learn from the outcomes of exploration wells drilled on neighboring blocks (Hendricks et al., 1987; Hodgson, 2024). Clearly, such delay undermines the value of social learning.

Yet natural models of social learning do not induce such delay without additional frictions. In Chamley and Gale (1994)’s seminal model where players infer others’ private information from the timing of their actions, delay vanishes in the continuous-time limit. And in Board and Meyer-ter-Vehn (2024)’s model of strategic experimentation, social learning reduces but never delays experimentation.

The purpose of this paper is to trace such lack of delay in social learning to a common cause, namely that social learning is *endogenously decision-irrelevant*: While the expected value of investing is subject to equilibrium learning, it remains weakly positive after any realization. Social information thus has no value and players prefer to invest immediately rather than delay even infinitesimally.

We show that decision-irrelevant social learning arises endogenously from natural asymmetries in two variants of a simple continuous-time model where two players, Iris and John, choose when to take an irreversible action/investment. First, we consider learning from others’ outcomes (e.g. side effects of the COVID vaccine, or the amount of oil discovered) while allowing for some outcomes being indistinguishable from inaction (e.g. the absence of side effects or the absence of investment success). [Proposition 1](#) shows that (symmetric) equilibrium features delay if and only if there exists an observable outcome that renders investment strictly unprofitable. Without such an outcome, only “no news” is bad news. In the unique symmetric equilibrium, players mix at time 0 between investing and not in a way that “no news” from John renders Iris indifferent about investment, and nobody invests

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thereafter. Equilibrium social learning is decision-irrelevant in that investment remains weakly optimal after any realization, eliminating incentives to delay investment.

Second, we consider learning from others' actions with private types, as in [Chamley and Gale \(1994\)](#). Since “investment” is irreversible while “non-investment” is temporary, only the highest types invest initially, so “investment” becomes a strong positive signal while “non-investment” is a weak negative signal. Again, the equilibrium chance of initial investment adjusts in a way that “non-investment” by John renders Iris's marginal type indifferent about investment, eliminating her incentives to delay.

The implications of good news and bad news signals for the decision-relevance of social learning has been observed in [Frick and Ishii \(2024\)](#)'s analysis of concave vs S-shaped investment dynamics in a binary-state model with exogenously delayed outcomes. The current paper highlights and extends this insight by eliminating exogenous delay, generalizing to arbitrary states and correlation of payoffs, and drawing the parallel to the observed action model. [Chamley and Gale \(1994\)](#) attribute the contrast of vanishing delay in their own paper, and delay in [Gul and Lundholm \(1995\)](#) to the action space, which is binary in the former and continuous in the latter. This paper traces back the cause further to the fact that the former, but not the latter renders social learning endogenously decision-irrelevant.

2. Model

Two players i, j , Iris and John, each choose whether and when to exercise an irreversible investment opportunity with uncertain value/outcome $X_i \in \mathcal{X} \subseteq \mathbb{R}$. First they simultaneously choose default times to invest $t_i, t_j \in \mathcal{T} := [0, \infty]$, with $t_i = \infty$ meaning never. If $t_i \leq t_j$, Iris invests at time $T_i = t_i$ and the game ends for Iris.¹ If $t_i > t_j$, the clock momentarily stops at t_j and Iris may get to revise her default time t_i by choosing $T_i \in [t_j, \infty]$. Iris's (discounted) payoff is $e^{-rT_i} X_i$. We consider two information structures.

Observable actions: Players have private types S_i . When $t_i > t_j$, Iris observes t_j and draws an inference about S_j before choosing T_i .

(Partially) observable outcomes: Some outcomes $\mathcal{X}^o \subset \mathcal{X}$ are observable. When $t_i > t_j$ and $X_j \in \mathcal{X}^o$, Iris observes X_j before choosing T_i . Other outcomes $\mathcal{X}^u = \mathcal{X} \setminus \mathcal{X}^o$ are unobservable, so when $X_j \in \mathcal{X}^u$ Iris observes nothing and sticks to the default $T_i = t_i$.

Outcomes and types (X_i, X_j, S_i, S_j) follow a joint distribution that is symmetric across players. For simplicity, we assume $\mathcal{X}$ finite with full-support prior p_x and, to avoid trivialities, $V := E[X] > 0$. We mostly focus on symmetric (perfect Bayesian) equilibria, but comment on asymmetric equilibria where convenient.

2.1. Remarks

As in [Gul and Lundholm \(1995\)](#), our continuous-time game and specifically Iris's instantaneous time- t_j reaction to John's time- t_j investment “should be considered as the limit of a series of discrete-time games as the length of the time between periods goes to zero”. Modeling our game directly in continuous-time is mostly for analytical convenience. It also avoids exogenous sources of delay associated with reacting some discrete time later, as in [Chamley and Gale \(1994\)](#) or [Frick and Ishii \(2024\)](#). Thus, any delay in our model arises endogenously from players' strategic attempts to socially learn.

We think it is important to consider social learning from both actions and outcomes since it may not be obvious which of the two channels is more relevant in practice, say for oil exploration. [Hendricks and Kovenock \(1989\)](#) study a model that nests both channels; for tractability they restrict attention to two periods. To study the length and the strategic nature of delay, we find it advantageous to study the two channels in two separate model variants. Relatedly, while our model bases Iris's learning from outcomes directly on John's payoffs X_j , the analysis would be unchanged if X_j was replaced with an arbitrary signal about X_j .

Both model variants are fundamentally asymmetric. Learning from outcomes makes the asymmetry explicit in its distinction between observable and unobservable outcomes, $\mathcal{X}^o, \mathcal{X}^u$. When learning from actions, the asymmetry arises more subtly from the fact that investment is irreversible while non-investment is temporary.

2.2. Preliminary analysis

When Iris observes John's action/outcome at $t_j < t_i$, she knows that no further information is forthcoming, so she invests either immediately or never for an expected payoff of $\max\{e^{-rT_i} E[X_i | S_i, t_j], 0\}$ with observable actions and $\max\{e^{-rT_i} E[X_i | X_j], 0\}$ with observable outcomes. Our analysis thus reduces to solving for static Nash equilibrium in default times $t_i, t_j \in \mathcal{T}$.²

We say that learning features *delay* if $t_i \in (0, \infty)$ with positive probability. Similarly, we say that learning is *incomplete* if $t_i = \infty$ with positive probability; in the converse cases we say that learning is *immediate/complete*.³

¹ Throughout, we describe and analyze the game from Iris's perspective, omitting the analogous arguments for John.

² The one potential wrinkle with the static game is that it fails to specify Iris's beliefs, reactions, and payoffs after off-path investment times $t_j < t_i$ with observable actions. But since John cares about Iris's actions only via the associated social learning from her investment, and can trigger her investment only by investing himself (after which he no longer benefits from social learning), the perfect Bayesian equilibria of our dynamic game are outcome-equivalent to the Nash equilibria of the static game for any specification of Iris's off-path payoffs.

³ While $t = \infty$ technically corresponds to infinite delay, we reserve the term “delay” to its common usage where it is finite. Complete learning is conceptually distinct from the notion of asymptotic learning in the social learning literature with exogenous timing following ([Bikhchandani et al., 1992](#)). Both notions pertain to the social information underlying late actions. But while the former requires all social information from a single opponent to become available, the latter requires the aggregate learning from an exploding sequence of others to fully reveal the underlying state.

Example 1. Applied papers on social learning from outcomes (e.g. Frick and Ishii, 2024; Baccara et al., 2024) typically assume binary, perfectly correlated outcomes $X_i = X_j \in \mathcal{X} = \{-L, H\}$ with perfect good news learning, $\mathcal{X}^o = \{H\}$, $\mathcal{X}^u = \{-L\}$, or perfect bad news learning, $\mathcal{X}^o = \{-L\}$, $\mathcal{X}^u = \{H\}$. Kartik et al. (2024) highlights the limitations of binary models for social learning with exogenous timing, so extending endogenous timing models beyond binary outcomes seems warranted. $\triangle$

3. Observable outcomes

We first consider observable outcomes. Write $F_t = \Pr(t_i \leq t)$ for the cdf of default investment times in a symmetric, mixed-strategy equilibrium, and f_t for the pdf (if it exists).

Let $V_t := E[X_i | X_j \in \mathcal{X}^u \text{ or } t_j > t]$ be Iris's expected value of investment when not observing John's outcome by time t ; we also define the expected values $V_\emptyset := E[X_i | X_j \in \mathcal{X}^u]$, $V_x := E[X_i | X_j = x]$ and $\underline{x} := \arg \min_{x \in \mathcal{X}^o} \{V_x\}$.⁴

Proposition 1. (a) *There is a unique symmetric Nash equilibrium.*

(b) *Learning features delay iff some observable outcome renders investment unprofitable, $V_{\underline{x}} < 0$.*

(c) *Learning is incomplete iff unobservable outcomes render investment unprofitable, $V_\emptyset < 0$.*

(d) *There are pure asymmetric equilibria $t_i = 0, t_j = \infty$ iff $V_\emptyset \leq 0$.*

Proof. First assume $V_{\underline{x}} < 0$, and consider Iris's problem of slightly raising her default investment time t , conditional on not having observed John's outcome yet. The flow-cost of waiting due to discounting equals rV_t . John's conditional rate of investing equals $\frac{f_t}{1 - p_{\mathcal{X}^o} F_t}$. And if John invests, Iris's value of social learning equals $\sum_{x \in \mathcal{X}^o} p_x \max\{-V_x, 0\}$, accounting for the avoided investment losses after John's observable outcomes with $V_x < 0$. Time- t indifference thus amounts to

$$rV_t = \frac{f_t}{1 - p_{\mathcal{X}^o} F_t} \sum_{x \in \mathcal{X}^o} p_x \max\{-V_x, 0\}. \quad (1)$$

Equilibrium mixing implies that the indifference condition (1) must hold on the interior of the support of F . Standard continuous-time war-of-attrition arguments imply that F is continuous with support $[0, T]$ for some $T \in \mathcal{T}$: If John invested at time t with positive probability, Iris would strictly prefer to postpone to learn from John's outcome, as witnessed by the RHS of (1) with " $f_t = \infty$ "; and a gap in the support of John's investment times $[t, \bar{t}]$ would induce Iris to front-load her investment from $\bar{t}$ to t , as long as her continuation value V_t is positive. All told, equilibrium is fully described by (1). This establishes part (a) when $V_{\underline{x}} < 0$, and the "if" direction of part (b).

Maintaining $V_{\underline{x}} < 0$, we turn to part (c). Intuitively, investment and learning continues as long as its continuation value V_t remains positive; since V_t tends to $V_\emptyset$ as $F_t \rightarrow 1$, complete learning hinges on the sign of $V_\emptyset$. Simple Bayesian accounting

$$V = F_t \sum_{x \in \mathcal{X}^o} p_x V_x + (1 - F_t p_{\mathcal{X}^o}) V_t = \sum_{x \in \mathcal{X}^o} p_x V_x + p_{\mathcal{X}^u} V_\emptyset$$

shows that V_t as a function of $F_t \in [0, 1]$ drifts continuously and monotonically from V to $V_\emptyset$, as illustrated by the straight arrows in the left panels of Fig. 1. If $V_\emptyset < 0$, V_t falls in F_t and approaches 0 as $F_t \rightarrow \bar{F} := V/(V - p_{\mathcal{X}^u} V_\emptyset) \in (0, 1)$. Learning is thus incomplete. Conversely if $V_\emptyset > 0$, then $V_t \geq \min\{V, V_\emptyset\} > 0$ lower-bounds f_t by (1), so $F_T = 1$ at some finite time T ; in the boundary case $V_\emptyset = 0$, F_t approaches but never reaches 1. Learning is thus complete. This establishes part (c) when $V_{\underline{x}} < 0$.

Now consider $V_{\underline{x}} \geq 0$. We can assume $V_\emptyset < 0$: Otherwise, if $V_\emptyset \geq 0$, investment remains optimal after every possible outcome of social learning and $t = 0$ is a dominant strategy, implying immediate, complete social learning, as illustrated in the upper right of Fig. 1.

The sum on the RHS of (1) is zero, intuitively requiring " $f_t = \infty$ " while $V_t > 0$. Formally, equilibrium is given by $F_t \equiv \bar{F}$ with continuation value $V_t \equiv 0$: Players are willing to invest at time 0 despite the imminent social learning because investment remains weakly optimal after every observable outcome (since $V_{\underline{x}} \geq 0$) and when nothing is observed at $t = 0$ (since $V_t = 0$); after time 0, players no longer care to invest because $V_t = 0$, as illustrated in the lower right of Fig. 1. Learning is immediate and incomplete. This establishes the "only if" direction of part (b), and part (c) when $V_{\underline{x}} \geq 0$.

We argue equilibrium uniqueness for $V_{\underline{x}} \geq 0$ by contradiction. Assume first an equilibrium with "more investment", $F_{t'} > \bar{F}$ for some $t' < \infty$ in the support of F ; since further investment is unprofitable, $V_{t'} < 0$, there can only be one such time t' and players invest at t' with positive probability. If John follows this strategy, default investment at $t_i = t'$ is not optimal for Iris: Waiting forever, $t_i = \infty$, allows her to invest at the same time whenever John invests with observable outcome $X_j \in \mathcal{X}^o$, but avoid investment and the associated loss $V_{t'} < 0$ in the event she does not observe John's outcome by time t' . Thus, such F is not a symmetric equilibrium. Assume next an equilibrium with "slower investment", $\underline{t} := \min_{t \in \mathcal{T}} \{F_t \geq \bar{F}\} > 0$. If John follows this strategy, investment remains optimal for Iris at every history before $\underline{t}$, $V_{\underline{x}} \geq 0$ and $V_t > 0$ for $t < \underline{t}$, so Iris strictly prefers to front-load all default investment from $(0, \underline{t}]$ to 0. Thus, such F is not a symmetric equilibrium either.

Part (d): Since $t_j = \infty$, Iris cannot learn from John and optimally invests immediately, $t_i = 0$. In turn $t_i = 0$ implies John's value of investing after not observing Iris invest at $t = 0$ equals $V_\emptyset$, so not investing $t_j = \infty$ when observing no outcome is optimal iff $V_\emptyset \leq 0$. $\square$

⁴ While the model is most interesting with both observable and unobservable outcomes, our results also apply in the extreme cases: When all outcomes are observable $\mathcal{X}^o = \mathcal{X}$, we simply set $V_\emptyset := V$, so by Proposition 1 learning is complete, and it features delay iff $V_{\underline{x}} < 0$. When all outcomes are unobservable $\mathcal{X}^u = \mathcal{X}$ there is no chance for social learning so players move immediately; technically we set $V_{\underline{x}} = \infty$, so together with $V_\emptyset = V$, Proposition 1 implies that learning is complete and immediate.

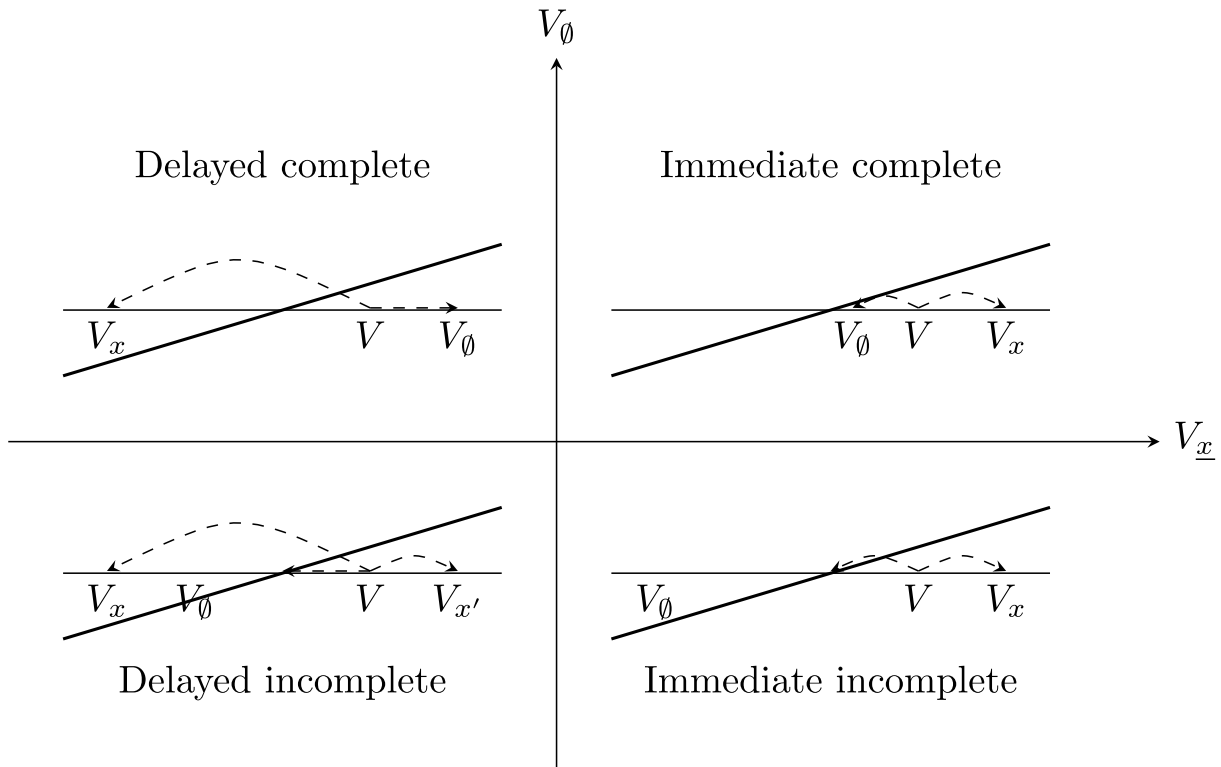


Fig. 1. This figure illustrates the dynamics of the continuation value V_i for the four cases where $V_x < 0$ (left), $V_x > 0$ (right), $V_\emptyset < 0$ (bottom), $V_\emptyset > 0$ (top). Curvy and straight arrows respectively indicate jumps and drift of V_i .

Example 1 continued. With perfect good news, $V_x = H > 0$ and $V_\emptyset = -L < 0$. By [Proposition 1](#), learning is immediate and incomplete with $F_i \equiv \bar{F} := V/(V + p_{-L}L)$; there are also two asymmetric equilibria, $t_i = 0, t_j = \infty$. With perfect bad news, $V_x = -L < 0$ and $V_\emptyset = H > 0$. By [Proposition 1](#) learning is delayed and complete with $rV_i = \frac{f_i}{1-p_{-L}F_i} p_{-L}L$. The two asymmetric strategy profiles, $t_i = 0, t_j = \infty$, are not equilibria. [Frick and Ishii \(2024\)](#) use this insight to argue that adoption curves are concave with good news learning, but S-shaped with bad news.⁵ $\triangle$

One might wonder what information structure maximizes players' welfare. However, mixed-strategy equilibrium logic tethers the symmetric equilibrium value to the single-player value V , so all the benefits of social learning and improved investment choices are dissipated by delay, as is common in a war of attrition with ex-ante homogeneous players. In the context of Example 1, bad news features both valuable social learning and costly delay, while good news features neither. To go beyond this irrelevance result, one might consider the asymmetric equilibrium or ex-ante heterogeneous players and richer information policies, as in [Knoepfle and Salmi \(2024\)](#).

4. Observable actions

To solve for equilibrium in the model with observable actions, we assume throughout that types (S_i, S_j) are distributed on $[0, 1]^2$ with continuous pdf ϕ , bounded away from 0 and ∞ , and that $V(S_i, S_j) = E[X_i|S_i, S_j]$ is continuous in (S_i, S_j) . We consider two cases.

Aligned values: Types (S_i, S_j) are positively affiliated, i.e. $\log \phi(S_i, S_j)$ is supermodular in (S_i, S_j) , and $V(S_i, S_j)$ rises in S_i and S_j .⁶ These are standard assumptions in the literature that fit well common applications, like the COVID-vaccine or oil exploration.

Opposed values: Types (S_i, S_j) are negatively affiliated, i.e. $\log \phi(S_i, S_j)$ is submodular in (S_i, S_j) , and $V(S_i, S_j)$ rises in S_i but falls in S_j , with $V(s, s) < 0$ for all s . These non-standard assumptions may capture situations where players are conducting R&D on mutually exclusive hypotheses, as in [Klein and Rady \(2011\)](#).

In either case, $E[X_i|S_i]$ rises in S_i , and we assume that $E[X_i|S_i = s^*] = 0$ for some $s^* \in (0, 1)$. We restrict attention to symmetric equilibria in monotone strategies, where the default investment time as a function of a player's type $t(s)$ is weakly decreasing.⁷ With

⁵ The finding of equilibrium delay under bad news but not good news is mirrored in the strategic experimentation literature where experimentation is delayed in [Bonatti and Hörner \(2017\)](#) but not in [Board and Meyer-ter-Vehn \(2024\)](#).

⁶ For concreteness, assume that all monotonicity assumptions are strict unless noted otherwise.

⁷ Monotonicity may be implied by equilibrium, but it is not obvious how to prove this.

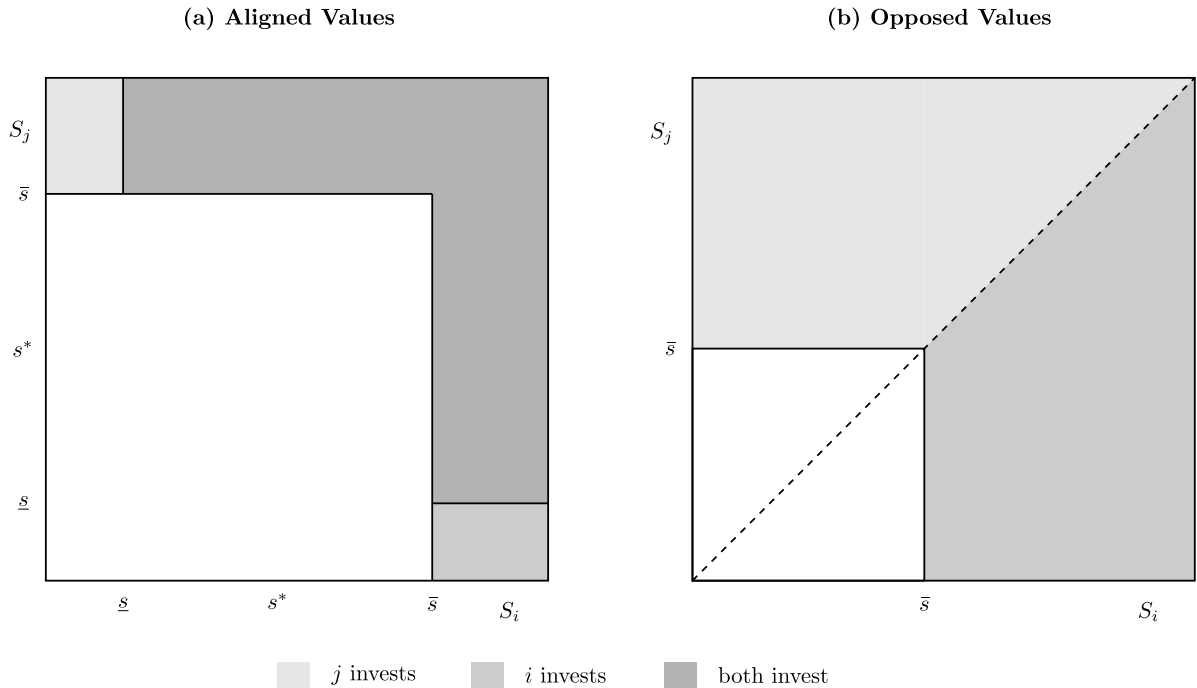


Fig. 2. Investment outcomes.

aligned values, observing the opponent invest (in a monotone equilibrium) is good news and triggers follow-up investments by lower types; in contrast, with opposed values it is bad news and forestalls follow-up investment. Fig. 2 illustrates both cases.

Our assumptions imply that the expected value $W(s) := E[X_i | S_i = s, S_j \leq s]$ is continuous with $W(0) < 0 < W(1)$; let $\bar{s} \in (0, 1)$ be its greatest root and assume $W(s)$ crosses 0 at $\bar{s}$.⁸ With aligned values, conditioning on $S_j \leq s$ lowers the expectation of X_i and so $\bar{s} > s^*$; with opposed values, it raises the expectation and so $\bar{s} < s^*$.

Proposition 2. (a) *There is a unique symmetric equilibrium in monotone strategies.*

(b) *Aligned values: there is no delay and learning is incomplete, $t(s) = 0$ if $s > \bar{s}$ and ∞ if $s < \bar{s}$.*

(c) *Opposed values: there is delay and learning is incomplete: $t(s)$ starts at $t(1) = 0$ and follows*

$$rW(s) = \frac{1}{t'(s)} \frac{\phi(s, s)}{\int_0^s \phi(s, \hat{s}) d\hat{s}} V(s, s); \quad (2)$$

types $s < \bar{s}$ never invest, $t(s) = \infty$.

Proof. Part (b): To verify equilibrium, assume John follows $t(s)$, so any delay allows Iris to learn whether $S_j > \bar{s}$ (if John invests at $t = 0$) or $S_j < \bar{s}$ (if he does not). Types $S_i > \bar{s}$ prefer to invest in either case, so optimally choose $t(s) = 0$. Types $S_i < \bar{s}$ prefer not to invest conditional on $S_j < \bar{s}$, so optimally choose default time $t(s) = \infty$; if John invests at time 0, Iris follows suit immediately if $E[X_i | S_i, S_j \geq \bar{s}] > 0$, which is the case iff $S_i > \underline{s}$ for some cutoff $\underline{s} < \bar{s}$. The equilibrium is illustrated in Fig. 2.

Uniqueness (with aligned values) follows as with observable outcomes and $V_{\underline{x}} \geq 0$, arguing by contradiction. Assume first an equilibrium $t(s)$ with “more investment”, $t(s') = t' < \infty$ for some $s' < \bar{s}$; since the profits of investment after t' are upper-bounded by $W(s') < 0$, there can be only one such time t' and a non-trivial interval of types invests at t' . If John follows this strategy, default investment at t' is not optimal for $S_i = s'$: Waiting forever, $t_i = \infty$, allows Iris to invest at t' whenever $t(S_j) = t'$, but avoid investment and the associated payoff, upper-bounded by $W(s') < 0$, when $t(S_j) > t'$. Thus, such $t(s)$ is not a symmetric equilibrium. Assume next an equilibrium with “slower investment”, $t(s') = t' > 0$ for some $s' > \bar{s}$. If John follows this strategy, investment remains optimal for $S_i = s'$ at every history before t' , $E[X_i | S_i = s', S_j \leq s] \geq W(s') > 0$ and $E[X_i | S_i = s', S_j = s] > 0$ for all $s \geq s'$, so Iris strictly prefers to front-load all default investment from $t(s')$ to 0. Thus, such F is not a symmetric equilibrium either.

Part (c): In equilibrium, $t(s)$ decreases strictly and continuously: If $t(s) \equiv t$ on $[\hat{s}, \bar{s}]$ then type $S_i = \hat{s}$ would wait an instant to see whether j invests $S_j \in [\hat{s}, \bar{s}]$, and then avoids investing herself; if $t(s) > t^+(s) := \lim_{\epsilon \rightarrow 0} t(s + \epsilon)$ there is no point in waiting, and s frontloads investment to $t^+(s)$. Writing $s(t)$ for the inverse of $t(s)$, the payoff of type s from investing at t is $\Pi(t, s) := e^{-rt} \int_0^{s(t)} V(s, \hat{s}) \phi(s, \hat{s}) d\hat{s}$.

⁸ For aligned values, $W(s)$ rises in s , so its root is unique and $W(s)$ must cross 0 at $\bar{s}$.

Taking the FOC wrt t and dividing by $e^{-rt} \int_0^s \phi(s, \hat{s}) d\hat{s}$ for consistency with (1) yields the FOC (2). Global optimality follows as usual by noting that $\frac{\partial \Pi(t, s)}{\partial t}$ single-crosses from above in s .⁹ $\square$

The equilibrium with aligned values corresponds to the equilibrium with observable outcomes when $V_\theta < 0 < V_x$, e.g. with common binary values and good news learning. Intuitively, observing investment is good news with aligned values.¹⁰ The equilibrium with opposed values corresponds to the equilibrium with observable outcomes when $V_\theta > 0 > V_x$, e.g. with common binary values and bad news learning. Intuitively, observing investment is bad news with opposed values.

The welfare neutrality result with observable outcome does not translate readily to observable actions because the cases of aligned values and opposed values differ in terms of preferences as well as information, undermining clean welfare comparisons. At an intuitive level, though, one might argue that the equilibrium under opposed values trades off delay costs for more precise learning and improved investment decisions compared to the case of aligned values.

5. Conclusion

The analysis of two simple social learning games shows that equilibrium delay can be undermined by decision-irrelevance, which arises naturally when learning from actions under aligned values, and when learning from good news outcomes. When “no news” is the only bad news, the equilibrium chance of initial investment adjusts in a way that “no-news” renders players indifferent about subsequent investment. Ironically, while investment remains weakly optimal and learning is irrelevant for the optimal action, learning is relevant for the equilibrium-path action since equilibrium relies on players breaking the indifference in favor of not investing after no news.

Empirically, evidence of delay points to the relevance of learning from bad news outcomes, which is natural in the context of the COVID-19 vaccine; in the context of oil exploration, it suggests that companies can observe others’ failed explorations as well as their successes. Conversely, the absence of strategic delay may present empirically in terms of Frick and Ishii (2024)’s concave adoption curves; these have been documented for “leisure-enhancing innovations such as movies” for which making a best-of list constitutes good news.

Theoretically, one may wonder how the delay in our two-player game would shape investment dynamics when there are more players, as in Murto and Valimäki (2011), Baccara et al. (2024), or Frick and Ishii (2024). We leave this interesting question for future work.

AI statement

During the preparation of this work the author used ChatGPT to tighten the language in some parts of the paper, including the abstract and this statement, and refine.ink to check the formal arguments. After using these tools, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Data availability

None.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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⁹ Indeed, noting $V(s, s) < 0$ and $\frac{ds(t)}{dt} < 0$, log-submodularity of $\phi(s, \hat{s})$ and monotonicity of $V(s, \hat{s})$ in s imply for $s = s(t) < s'$ that

$$\begin{aligned} 0 &= e^{rt} \frac{\partial \Pi(t, s)}{\partial t} = -r \int_0^s V(s, \hat{s}) \phi(s, \hat{s}) d\hat{s} + \frac{ds(t)}{dt} V(s, s) \phi(s, s) > -r \int_0^s V(s, \hat{s}) \phi(s', \hat{s}) d\hat{s} + \frac{ds(t)}{dt} V(s, s) \phi(s', s) \\ &> -r \int_0^s V(s', \hat{s}) \phi(s', \hat{s}) d\hat{s} + \frac{ds(t)}{dt} V(s', s) \phi(s', s) = e^{rt} \frac{\partial \Pi(t, s')}{\partial t} \end{aligned}$$

¹⁰ There may be asymmetric equilibria. Generalizing the cutoff strategies from part (b) to general cutoffs z , write $\gamma(z)$ for the cutoff of the best response, i.e. the unique root of $E[X_i | S_i = \gamma(z), S_j \leq z] = 0$. The symmetric equilibrium satisfies $\gamma(\bar{s}) = \bar{s}$, but if $|\gamma'(\bar{s})| > 1$ there are other equilibria with $\gamma(\bar{s}_i) = \bar{s}_j$ and $\gamma(\bar{s}_j) = \bar{s}_i$.

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