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Paper to be presented at  
the DRUID16 20th Anniversary Conference  
Copenhagen, June 13-15, 2016

## **The Curse of Knowledge - When Positive Knowledge Turns Negative**

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### **Abstract**

There is much consensus that knowledge is an important and valuable resource in many industries. In the context of organizational choice and decision-making, knowledge is valuable because it allows firms to make informed and better choices. This seems to be particularly true for positive knowledge, i.e., knowledge about successes or above-average alternatives ("knowing what does work"). Using an n-armed bandit model, we examine when positive and negative knowledge (i.e. "knowing what does not work") is particularly valuable (or even costly). We show that while the value of negative knowledge is always positive, positive knowledge may have negative performance effects. . The findings of our study have important implications for the study of choice and learning under uncertainty, learning from success and failure, and knowledge as strategic asset.

## **THE CURSE OF KNOWLEDGE - WHEN POSITIVE KNOWLEDGE TURNS NEGATIVE**

There is much consensus that knowledge is an important and valuable resource in many industries. In the context of organizational choice and decision-making, knowledge is valuable because it allows firms to make informed and better choices. This is particularly true for positive knowledge, i.e., knowledge about successes or above-average alternatives (“knowing what does work”). Indeed, one fundamental premise of rational accounts of choice is that knowledge always has a non-negative value. Using an n-armed bandit model, we demonstrate that while this is true for unique, non-recurring choices, it may not be true for recurring choices that allow for learning. With recurring choices, positive knowledge can hurt performance while the value of negative knowledge (“knowing what does not work”) always remains non-negative. The findings of our study have important implications for the study of choice and learning under uncertainty, learning from success and failure, and knowledge as strategic asset.

(Keywords: behavioral theory of the firm, positive and negative knowledge, armed bandit model, choice and learning under uncertainty)

*The only consultants I've ever hired in my 10 years is one firm to analyze Gateway's retail strategy so I would not make some of the same mistakes they made.*

Steve Jobs FORTUNE 2008

## **Introduction**

Knowledge is often portrayed as the most critical source of competitive advantage in many industries (Nelson and Winter 1982; Winter 1987, Kogut and Zander 1992; Grant 1996). In the context of a behavioral perspective on organizational choice and decision-making (Simon 1947; Cyert and March 1963; Argote and Greve 2007; Gavetti, Levinthal, and Occasio 2012) knowledge is so important because it allows organizations to make informed and better choices. In choice situations both endowments with “positive knowledge”, knowledge about above average choices (knowing what does work) and “negative knowledge”, knowledge about below average choices (knowing what does not work), are valuable (Adner and Levinthal 1992; Teece 1981, 1998, 2002). Positive knowledge allows organizations to pick attractive alternatives while the negative knowledge allows firms to avoid unattractive alternatives and explore (potentially) more promising alternatives (as in Steve Jobs' opening quote). What is the (relative) value of positive and negative knowledge in various choice situations? When are positive and negative knowledge are particularly valuable or even costly. In our study, we use a standard n-armed bandit model to make some headway into answering these questions.

In the standard formulation of this model, agents are initially endowed with un-informed, flat zero beliefs. Through noisy performance feedback, the agents have to learn about the values of their alternatives. The higher the level of noise (or uncertainty) is, the more difficult and error prone the agents' learning becomes. We incorporate the idea of positive and negative knowledge by endowing agents with some knowledge about attractive (positive knowledge) and unattractive (negative knowledge) alternatives. We find that negative knowledge is increasing in uncertainty; for positive knowledge, we observe a different pattern. In the absence of uncertainty, positive knowledge is more valuable than negative knowledge. For low levels of uncertainty, its value can be negative. Only for high levels of uncertainty, it becomes more valuable than negative knowledge again.

The notion that knowledge always has a non-negative value is also one of the fundamental premises of expected utility theory (Savage 1954). Similarly, less rationale accounts of organizational choice and decision making that depict organizations as adaptive systems (Cyert, and March 1963, Levinthal 1997) also point to the non-negative value of knowledge (Gavetti and Levinthal 2000; Rivkin 2001). In a one-shot choice situation, positive knowledge is particularly valuable and neither positive nor negative knowledge can have negative effects on decision performance, regardless of payoff distributions, the number of possible alternatives, and so on. In the worst case, the value of knowledge converges to zero if there are many alternatives and the firm is endowed with negative knowledge, or if the firm is endowed with positive knowledge about an alternative that is only marginally better than zero.

It seems self-evident that positive and negative knowledge can only improve organizational decision-making. This is certainly true if we consider only non-recurring decisions like the one in the example above, that is non-repeated, completely unique choices. Yet, many organizational decisions are recurring and offer opportunities for learning (e.g., March and Olsen 1975; Greve 2000, Eggers 2012). In that case, a firm's initial endowment with (positive or negative) knowledge is only the starting point for its subsequent learning process. We demonstrate that despite its strong positive effect in the short-run, positive knowledge can become a liability in the long run when learning is possible. Then, being endowed with no knowledge can be better than having positive knowledge. It is important to note that we observe these negative effects of a positive knowledge endowment even if this endowment is completely accurate. We also rule out the possibility that knowledge that once was accurate becomes outdated and misleading because of, for example, environmental dynamics.

How can positive (and accurate) knowledge ever become a liability? We know from prior research that if knowledge has become obsolete (Anderson and Tushman, 1990; Henderson and Clark, 1990; Levinthal and March, 1993; Tushman and Anderson, 1986), outdated (Siggelkow, 2002; Tripsas, 2009; Tripsas & Gavetti, 2000), or misleading (Leonard-Barton, 1992; Levinthal & March, 1993), it may become a liability. Yet, in our model, if an agent is endowed with (positive or negative) knowledge, his initial belief on a particular alternative is set to its true value. Thus, this knowledge

endowment is always correct. These correct initial beliefs, however, may also increase the perceived opportunity costs of exploration. The “bird in the hand” appears to be rather attractive compared to exploring “the bush”. Without any positive knowledge endowments, the perceived opportunity costs of exploration are much lower. There is not too much to lose through exploration. As a result, agents not endowed with any positive knowledge explore much more. In environments of high uncertainty, this exploration-suppressing effect of positive knowledge has no negative effects. Uncertainty itself introduces sufficient, if not too much exploration. In low uncertainty environments, however, this exploration-suppressing effect may result in insufficient exploration and, in turn, sub-optimal performance.

As a result, a firm would be better off ignoring (or forgetting) this positive knowledge, despite the fact that it is entirely correct and valuable at least in the short-run. Experimental studies, however, have demonstrated that ignoring knowledge is difficult –the “curse of knowledge” (Camerer, Loewenstein, and Weber 1989; Heath and Heath 2006). With negative knowledge, in contrast, we do not observe these negative long-run effects. Negative knowledge should never be ignored and should always be taken into account. It makes firms avoid unattractive alternatives, thereby increasing the expected value of exploration, making it more attractive.

Our findings on negative knowledge also echo observations by industry experts that negative knowledge is “one of the most readily overlooked parts of a company’s knowledge assets” (Hodgson 2001: p.45). For instance, consider the drug discovery process. Obviously, it is valuable to know whether a specific compound is particularly promising. At the same time, knowing which compounds do not work also saves time and costs. In fact, more recently, some courts have recognized such negative knowledge as a (valuable) trade secret (Graham 2008).

We are not the first to claim that knowledge may have negative implications. For example, Haas and Hansen (2005) argue that utilizing knowledge to complete sales bids for consulting projects can hurt performance. Similarly, Henderson and Clark (1990) argue that prior knowledge may even “blind firms” and that such prior knowledge may “not only not useful but may actually handicap the firm” (p.13). In these and related studies, however, the definition of knowledge is less restrictive than

in our study: in our study, all knowledge endowments are always correct, never misleading, erroneous, or outdated. Empirical studies often face the challenge to measure the accuracy of knowledge. As a result, less restrictive definitions of knowledge are adopted (we would call this “beliefs” rather than knowledge) and it is less surprising that knowledge can have negative implications if it can also imply incorrect or outdated beliefs. Research on herding also points to the negative implications of knowledge. If there are some strategic interactions, ignoring own, correct knowledge can enhance performance if there are knowledge asymmetries (Abrahamson and Rosenkopf 1993; Camerer, Loewenstein, and Weber 1989; Banerjee 1992, Bikhchandani, Hirshleifer, and Welch 1992). Our study, however, focuses on the choice behavior of a singular firm, setting aside any strategic interactions with other firms.

In sum, our paper contributes to the existing literature by identifying the conditions under which positive and negative knowledge are particularly beneficial or costly. Research on the relative value of positive and negative knowledge has generated mixed evidence. Existing research, in particular on benchmarking (Cox, Mann, and Samson, 1997) and transfer of best practices (Winter and Szulanski 2001) highlights the value of positive knowledge. More recent research, however, has also depicted negative knowledge as an important knowledge asset within firms (Hodgson 2001; Thomke 2003). We demonstrate that value of positive and negative knowledge is a function of the level of environmental uncertainty and the existence of opportunities for learning and improving the positive or negative knowledge endowment. We also demonstrate that the strength of a firm’s beliefs in these knowledge endowments is an important moderator and show that positive and negative knowledge differ in the way their value is affected by errors. Finally, we uncover the mechanisms that determine the value of positive and negative knowledge in different contexts. These findings motivate new directions for research on the value of knowledge in choice situations and may redirect our attention towards negative knowledge.

The remainder of this study is structured as follows: First, we review the relevant theoretical building blocks on positive and negative knowledge for organizational choice and learning. Second, we describe our analytical and modeling approach. In section four, we present the results of our

simulation experiments on the implications of endowing firms with more or less positive or negative knowledge in choice problems. Finally, we conclude with a discussion of implications for theory and practice.

### **3. Model**

To study the implications of positive and negative knowledge on organizational choice and learning, we use a standard multi-armed bandit model (Gittens 1979; Sutton and Barto 1998; Posen and Levinthal 2012). In the bandit model, an agent has to choose one of the  $n$  available alternatives in each period. This choice then generates a performance signal and the agent uses this signal to update its belief about the payoff of this particular alternative; the agent's beliefs on the other choices are not updated. This updating or learning process becomes non-trivial if there is uncertainty, that is if the signal is conflated by noise. As in Sutton and Barto (1998), we also always draw this noise term from a standard normal distribution. While noisy, the signal is unbiased. Agents are assumed to update their beliefs through a simple averaging mechanism (Sutton and Barto 1998); their current belief on a particular choice equals the average of all prior signals on this particular choice. The agents start their learning process from uninformed, flat beliefs; their initial beliefs are zero for all alternatives. Formally, we assume that in each period, the agents choose on the basis of their beliefs. Specifically, the agent picks the alternative that it believes is associated with the highest expected value. All these assumptions are consistent with a standard  $n$ -armed bandit model (Sutton and Barto 1998).

We build on this canonical model by examining the implications of positive and negative knowledge on organizational choices and performance (see also Figure 1). Being endowed in  $t=0$  with (one piece of) positive knowledge implies that a firm starts its learning process with a correct prior on one of the alternatives with a positive payoff; being endowed with negative knowledge implies that it starts its learning process with a correct belief on one alternative with a negative payoff. We then identify conditions under which positive and negative knowledge may have negative implications for organizational decision performance. We also identify the mechanisms that are responsible for this effect. In the remainder of this section, we discuss our assumptions in more detail.

#### *Positive and Negative Knowledge*

In our extension of the standard model, the firm is endowed with a correct prior on one arm and unbiased, flat priors on the remaining arms. The correct prior on one arm reflects one piece of knowledge. This knowledge can be positive or negative knowledge. It is positive knowledge if it is about an arm with a positive payoff; it reflects negative knowledge if it is about an arm with a negative payoff. Technically, we implement these two types of knowledge in the following way: first, we set all priors to zero, the (expected) mean of the payoffs across all arms. This guarantees that agents hold unbiased beliefs. Second, we randomly choose one arm with a positive (negative) payoff and endow the agent with this knowledge by setting his prior on this arm to the payoff of this arm.

### *Organizational Choice and Learning*

Organizations are thought to choose on the basis of their beliefs: specifically, they always choose the alternative that they believe is associated with the highest payoff (we relax this assumption later on in our analysis). In the context of repeated choices, firms update their beliefs on the basis of the performance feedback that they generate through their choices. Thus, a firm's knowledge endowment (or priors) is only the starting point for the firm's subsequent experiential learning process. Once a firm has chosen a particular alternative  $i$ , this action generates a reward - a noisy signal of the true payoff of this choice. Based on the outcome of this choice, the firm updates its beliefs on the payoffs of this choice. Specifically, we assume that an agent's belief of the value of a particular alternative equals the average over all signals it has received for this particular alternative. If he is endowed with (positive or negative) knowledge about this particular arm, this knowledge is understood as the first signal.

Several properties of this choice and learning process are noteworthy. An experimental learning process implies that only one alternative is explored at a time and that different alternatives can only be explored sequentially rather than in parallel (Gavetti and Levinthal 2000). These properties may not characterize all organizational choice processes but important strategic choices (for example, the question in which market to expand next, which new product to launch, which firm to acquire next). With other, more mundane organizational choices, organizations may have the capacity to explore several alternative courses of action at the same time like for example, alternative ways to

repair copying machines (Brown and Duguid 1991) or alternative sales techniques (Chan, Li, and Pierce 2012). Our focus is on the value of positive and negative knowledge in these settings.

Choosing the alternative that is believed to generate the highest payoff is what Sutton and Barto (1998) call a “greedy” choice rule. For one-shot choices, this is obviously the most efficient choice rule. With repeated choices (and the opportunity to learn more about the value of choice), other, less-greedy choice rules might be better. Less-greedy choice rules induce exploration, thereby creating more opportunities for learning about other alternatives. As we will demonstrate below, less-greedy choice rules affect our key findings quantitatively but not qualitatively. The same holds for alternative learning and updating rules; the general pattern of results remains unaffected.

Finally, our model makes some (implicit) assumptions about what agents know beyond the positive and negative knowledge he is endowed with. First, they do not have to discover the alternatives; they know there are  $n$  alternatives. Second, they also know that the mean payoff across all alternatives is zero; for those arms for which they are not endowed with positive or negative knowledge or have not acquired experience, their beliefs are initially all set to zero. Agents do not have any knowledge or form beliefs about the variance of payoffs. These assumptions are not idiosyncratic: all models derived from the standard  $n$ -armed bandit model rest on these assumptions (e.g., Denrell and March 1991; Posen and Levinthal 2012)

#### **4. Analysis**

In our baseline model, the organization has to choose among 10 alternatives. All results are based on 200,000 replications. Consistent with economical approaches (Arrow 1962, Hirshleifer 1973), we measure the value of (positive or negative) knowledge as the difference in performance between informed and uninformed choices. In Figure 3, we focus on the average value of positive and negative knowledge for one-shot choices (after one period, panel A) and repeated choices (over 100 periods, panel B). Performance is normalized by subtracting the corresponding average performance of uninformed, random choices.

< Insert Figure 3 about here >

Not surprisingly, we find that both positive and negative knowledge are always valuable in the short-run (panel A). A piece of positive knowledge, however, is much more valuable than negative knowledge (10x more valuable). As described in the introductory example, positive knowledge is valuable because it guides the organization to attractive choices. Firms should choose the alternative for which it is endowed with positive knowledge. However, negative knowledge is also valuable because it makes firms avoid unattractive choices. A firm that has (negative) knowledge on an alternative with a negative payoff can avoid this arm. Excluding the negative arm from the consideration set increases the expected value of choosing among the remaining alternatives, even if this choice is completely random.

In sum, consistent with prior research on rational choice (von Neumann and Morgenstern 1944, Savage 1954) we find that both kinds of knowledge always have a non-negative value. It is easy to demonstrate that this non-negative effect is independent of, for example, the distribution of the payoffs and the number of available choices. The value of both positive and negative knowledge may converge to zero if, for example, the number of alternatives is very high (in the case of negative knowledge) or the alternative for which the firms is endowed with knowledge is only marginally better than zero (in the case of positive knowledge). However, there is no choice problem for which a knowledge endowment is negative.

Once firms can repeatedly choose among the same set of choices and, by implication, learn from intermediate performance feedback, these results on the value of positive and negative knowledge are overturned. Recall that with repeated choices, a firm's endowment with positive or negative knowledge is only the starting point for its own experiential learning process. As we demonstrate below (Figure 4), our results also hold, and are more pronounced, for the case that firms do not update their beliefs on those choices for which they are endowed with knowledge. In Figure 3, panel B, we repeat the analysis of Figure 1 for 100 periods and report the cumulative average performance over these 100 periods. Rather than choosing only once, a firm chooses repeatedly among the same set of choices. These repeated choice open up the opportunity for learning. Based on the feedback of its choices, the firm updates its expectations. This is particular important for the arms on which the firm is not endowed with any knowledge.

Yet, we find that if firms can learn and improve their initial knowledge endowment, positive knowledge endowments are no longer positive; performance drops below zero and a firm would be better off not having this knowledge at all (or not acting on it, we will return to this aspect below). Recall that these knowledge endowments are accurately reflecting the payoffs of the underlying choices and that the payoffs do not change in our setup. Negative knowledge, in contrast, loses much of its value but never becomes a liability.

In sum, positive knowledge is particularly valuable if there are no opportunities for learning. Yet, once firms can learn, positive knowledge can become costly. Negative knowledge, in contrast, while less valuable for one-shot decisions, also loses its value if there are opportunities for learning but its value never turns negative.

In figure 4, we systematically examine the value of knowledge for different time horizons (x-axis). The dashed line shows the value of positive knowledge, i.e. knowledge about of the alternatives with positive payoffs; the solid line shows the average value of negative knowledge, i.e. knowledge about alternatives with negative payoffs. The dotted line shows the average performance of agents endowed with no knowledge.

< Insert Figure 4 about here >

Early on, with only a few opportunities for learning, the value of knowledge is positive. The average value of positive knowledge is substantially higher than the value of negative knowledge. After only a few periods, this picture changes completely. Negative knowledge is still valuable (for very long time horizons, it converges to zero); yet, positive knowledge turns negative and, as a result, the value average knowledge also turns negative.

In sum, positive knowledge is most valuable in the short-run, i.e., if opportunities for learning are scarce. In the long run, with more opportunities for learning, the value of positive knowledge can turn negative. Negative knowledge, in contrast, is less valuable in the short run and also loses its value over time but it never turns negative. The negative long-run effect of positive knowledge is much stronger than the positive effect of negative knowledge. As a result, the average value of a piece

of knowledge (either positive or negative) becomes negative over time. In the following two sections, we seek to uncover the mechanisms that drive these results.

### *Negative Knowledge: Underlying Mechanisms*

Negative knowledge does not tell a firm what to do, only what not to do. Negative knowledge helps firms avoid unattractive, below-average alternatives. Processes of learning from experience can generate very reliably this negative knowledge (March 1996, Denrell and March 2001). An organization that learns from its experience will never end up sticking to a negative alternative. If there are opportunities for learning (because choices are recurring), sooner or later, organizations will recognize unattractive alternatives as unattractive.; in the presence of uncertainty, even an unattractive choice may appear attractive for some time because the organization receives chance-positive signals about its value and it may take longer for the organization to form negative beliefs on this alternative. Yet positively inflated expectations can be only a transitory phenomenon. Thus, negative knowledge can provide organizations with a head start but given the reliability of experiential learning processes in generating negative knowledge, it cannot have a lasting effect on decision performance. This effect occurs independently of the specific implementation of the learning mechanism (as long as it is an unbiased learning mechanism).

The value of negative knowledge never becomes negative, even in the long run. In the short-run, however, negative knowledge is much less valuable than positive knowledge. Positive knowledge guarantees that the organization only picks positive alternatives; negative knowledge only removes one negative alternative from an organization's consideration set. Even after the removal of this one negative alternative, it may still include several other negative alternatives. Only in the extreme case of just two alternatives, negative and positive knowledge are equally valuable. As the number of negative alternatives increase, the value of negative knowledge decreases. Consider a choice problem with 1'000 alternatives, 500 with a positive payoff and 500 with a negative payoff. The average payoff across all choices is zero. An organization with negative knowledge on one alternative will avoid this arm and choose randomly among the remaining 999 alternatives. The expected value of such a choice is  $-x/999$ , with  $x$  the payoff of the known negative alternative. For example, even if we remove an extremely negative alternative with a payoff of -2.32 (if drawn from a standard normal distribution,

the likelihood that an alternative has a payoff of -2.32 or lower is only 1%) from a firm's consideration set, this improves choice performance by only  $2.32/999=0.0023$ .

*Positive Knowledge: Underlying Mechanisms*

Like negative knowledge, positive knowledge has positive performance effects in the short-run. Unlike negative knowledge, however, positive knowledge can have negative effects in the long run. Knowing and choosing the best alternative is always valuable. Thus, these negative effects must stem from positive knowledge about attractive but suboptimal positive alternatives. Recall that organizations will never converge to negative alternatives; any steady state performance differences must arise from different patterns in convergence to positive alternatives. Specifically, negative effects of positive knowledge must arise from an increased probability of sticking to positive but suboptimal alternatives.

Consider again the numerical example in the introduction (four alternatives, two positive alternatives with payoffs 2.0 and 1.0 and average payoff of 0). Knowing the value of and choosing the second best alternative is certainly valuable in the short run – its payoff of 1.0 is higher than that of an uninformed, random choice (with an expected payoff of 0.0). Yet, choosing this second best alternative also means that the firm forgoes the opportunity to explore and discover the best alternative. When making the trade-off between exploiting the second best alternative and exploring other alternatives, the firm playing the second best alternative faces high opportunity costs: the current choice appears very attractive (+1) while the average signal of exploring other alternatives is negative (-1). These high costs ( $-1.0-1.0=-2.0$ ) make exploration unattractive and unlikely.

Thus, firms may get stuck to a relatively attractive choice but not the most attractive one. This exploration-suppressing effect of positive knowledge is clearly desirable if the firm is endowed with positive knowledge about the best alternative. For other, positive but still suboptimal alternatives, however, it carries the cost of foregoing the chance of discovering an even better opportunity.

A positive knowledge endowment makes it more likely that a firm gets stuck. Consider two firms facing the choice problem described above. The first firm is endowed with positive knowledge about this second best alternative while the other firm has no knowledge but, by chance, also chooses

this second best alternative in the first period. They both receive a chance-negative signal (-0.2) in this first period. The first firm will lower its expectations from 1.0 to  $(1.0-0.2)/2=0.4$ . Even with this lower expectation, it still appears to be the most attractive alternative for the organization. The second firm, in contrast, with its zero prior for this alternative will lower its expectation from 0 to  $(0-0.2)/2=-0.1$ . Now, this alternative appears to be least attractive in the set of alternatives. Thus, accurate positive knowledge makes it more likely that a firm gets stuck to attractive but suboptimal solutions.

The strength of a firm's priors has an important moderating effect. Recall we assume that a firm's positive or negative knowledge is treated as one signal in the learning process. If treated as two signals, the first firm will update its expectations to  $(1.0+1.0-0.2)/3=0.6$ . If treated as three signals, i.e., stronger signal, the firm will update its expectations to  $(1+1+1-0.2)/3=0.7$ . If we treat a firm's knowledge endowment as less than "one signal", we can also consider less strong priors. For example, if we treat a firm's prior as only a 0.5x signal, the first firm will update its expectations to  $(0.5*1-0.2)/1.5=0.2$ . The stronger the priors, the lower the negative impact of this negative signal. The weaker the prior, the more likely that a chance-negative signal makes the firm believe that it has chosen an unattractive alternative. For example, with weak priors (such as a weight of only 0.2), a chance-negative signal smaller than -0.2 is enough to make the firm believe that this choice has a negative payoff.

< Insert Figure 5 about here >

In Figure 5, we examine the performance implications (y-axis) of varying the strength (x-axis) of a firm's knowledge endowment. It is important to note that the accuracy of a firm's priors is unchanged. As per the example above, however, priors may vary in their strength. In the extreme case of strength=0, a firm's priors affect only its first choice. After this first choice, the prior is replaced by the performance signal the firm received. In the other extreme, if priors are very strong, a firm hardly revises its priors to new information. The value of positive and negative knowledge is measured as the as the cumulative average performance over 100 periods minus the corresponding performance of an uninformed agent.

The strength of a firm's belief in its knowledge endowment has a negative effect for positive knowledge and no effect for negative knowledge. It has no effect for negative knowledge because firms will never choose alternatives that they believe are associated with negative payoffs, regardless of the strength of its belief in this knowledge. Negative knowledge makes firms avoid the corresponding alternatives and, as a result, do not update their beliefs. It is only in the process of updating beliefs that the strength of priors matters. In the choice process itself, the strength of priors do not matter.

With positive knowledge, less strong priors make firms less susceptible to getting stuck to positive but suboptimal alternatives. At the same time, however, chance-negative signals on the optimal alternative are more likely to make the firm believe that it is an unattractive alternative. Yet, the probability that a firm comes to believe that an alternative is negative is a function of the payoff of the alternative – the higher the payoff, the less likely it is that a firm forms a negative belief on this alternative. Put differently, the probability that a firm will get stuck to a particular alternative is decreasing in this payoff.<sup>1</sup>

Uncertainty, the level of noise in the performance signals the firm receives, also affects the probability that a firm get stuck at attractive but suboptimal solutions. Consider a firm that is endowed with positive knowledge about a choice that is associated with a payoff of 0.1. In the absence of uncertainty, all performance signals will be positive. There are no chance negative signals that might suggest that this is an unattractive alternative and firms never develop negative expectations on positive alternatives. As a consequence, absent a mechanism to induce some exploration (we will discuss this below), a firm may get stuck to alternatives that are only marginally positive. In Figure 6, we report the long-run performance effects (y-axis) of positive and negative knowledge for varying levels of uncertainty (x-axis).

< Insert Figure 6 about here >

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<sup>1</sup> These dynamics resemble those of search on a rugged landscape (Levinthal 1997): In rugged landscapes, higher peaks have larger basins of attraction, making it less likely that any error will make them abandon their current peak.

In the long run, knowledge is only valuable in the presence of uncertainty. In the absence of uncertainty, both positive and negative knowledge is worthless; an uninformed agent can achieve the same long-run performance levels by learning over time. Yet, while the value of negative knowledge is strictly increasing in the presence of uncertainty, the value of positive knowledge is positive in the absence of uncertainty, turns negative for low levels of uncertainty, and becomes positive for high levels of uncertainty, even exceeding the value of negative knowledge at some point.

Our finding that positive knowledge has a negative value for moderate levels of uncertainty is interesting because in decision-theoretical and neoclassical accounts (Arrow 1963, Hirshschleifer 1973), the value of knowledge<sup>2</sup> is measured as the most a decision maker would be willing to pay to resolve uncertainty. Accordingly, knowledge is understood as the negative measure of uncertainty (Hirshschleifer 1973, Arrow 1984). As uncertainty increases, this value should also increase. Our analysis points to a non-linearity in this relationship: we observe a positive relationship between uncertainty and the value of positive knowledge only if the level of uncertainty exceeds a particular threshold; below this threshold, the relationship can even be negative.

With this understanding of the underlying mechanisms, it also becomes clear that neither the number of alternative choices nor the distribution of the payoffs qualitatively affect our key findings. Similarly, a more exploratory choice rule can mitigate the negative long-run effects of positive knowledge but can never make positive knowledge valuable. A less-greedy choice rule (like, for example, a softmax (Posen and Levinthal 2012) or e-greedy choice rule (Sutton and Barto 1998)) induces firms to more readily abandon positive but less attractive alternatives. At the same, however, they also make it more likely that firms will (temporarily) abandon very attractive alternatives. Thus, while a remedy for the problem of positive knowledge on less attractive arms, such a choice rule comes at the cost of decreasing the value of positive knowledge on very attractive alternatives. In Figure 7, we report long-run performance of positive and negative knowledge for various levels of exploration, ranging from pure exploitation to pure exploration.

< Insert Figure 7 about here >

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<sup>2</sup> These streams of literature typically use the label “information” rather than knowledge.

With exploration rates below 0.25, the general pattern is unaffected: positive knowledge becomes negative in the long run while negative knowledge is always valuable. An exploration rate of 0.25 reflects the optimal exploration rate in our setup. With higher exploration rates, the agent suffers from overexploration. When overexploring, however, positive knowledge also becomes positive but never exceeds the value of negative knowledge.

In sum, the negative long-run effects of positive knowledge arise because positive knowledge makes firms more likely to stuck to positive but suboptimal alternatives. With less strong priors, this problem can be alleviated and, as a result, positive knowledge can become more valuable than negative knowledge even, in the long run. However, less strong priors create another organizational challenge. Organizations should act strongly on their knowledge endowments (they should always choose on the basis of their priors) but only with weak conviction (they would be willing to completely revise their priors once they receive a first signal). This seems almost schizophrenic, in particular in an organizational context: to persuade the organization to pursue a particular alternative, management has to demonstrate strong confidence that this alternative is the right course of action. At the same time, it must be willing to completely overthrow these convictions once a negative performance signal is received. Dealing with the tension between strong actions (always picking on the basis of the knowledge endowment) and weak beliefs might be quite challenging in many organizational settings.

### *When Positive and Negative Knowledge is Wrong*

In our analyses above, we assumed that if a firm is endowed with knowledge, this knowledge is always correct, never misleading, biased, or outdated: if a firm is endowed with knowledge about a particular alternative, this endowment equals exactly the payoff of this alternative. But a firm's knowledge endowment is often incorrect. For example, firms often rely on inapplicable analogies or mental models (Weick 1995) or outdated beliefs (Tripsas 2009). Firms suffer from errors of generalization (Walsh and Ungson 1991) and develop superstitious beliefs (March and Levinthal 1993, Denrell and March 2001, March 2011). When sourcing this knowledge externally, firms may source it from inappropriate targets (Greve 2011, Posen, Lee, Yi 2013, Williams 2007) or adopt it incorrectly (Winter and Szulanski 2001). As a result, organizations may come to believe that a particular alternative is attractive while indeed it is rather unattractive (i.e., it has a negative payoff). Similarly, organizations may come believe that a particular alternative is unattractive when it is really an attractive alternative.

< Insert Figure 8 about here >

Knowledge errors are always costly, in the short run and the long run (see Figure 8). If a firm is endowed with erroneous beliefs about a negative alternative, these errors are particularly costly. Holding positive beliefs about a negative alternative makes a firm choose this alternative. This choice is obviously worse than a random choice (with an expected value of zero). Over time, the firm will learn about the negative value of this alternative and correct this error. The same is true for errors with positive alternatives: holding negative beliefs about a positive alternative makes the firm choose (randomly) among the remaining alternatives. If the average over all payoffs equals zero, the expected value of choosing among the remaining alternatives is negative. In the long run, however, as the organization learns from its own experience, this negative effect further diminishes. Most interestingly, in the long run, a firm is better off (erroneously) believing that a positive alternative is actually a negative alternative than holding correct, positive expectations.

Recall from our previous analysis that positive knowledge might lock firms onto positive but suboptimal alternatives. This is particularly costly in the long run, when the opportunity costs of

finding an even better alternative are high and can outweigh the short-run benefits of positive knowledge in picking a positive alternative. With negative beliefs on a positive alternative, these short-run benefits cannot be realized. At the same time, however, the long-run problems of positive knowledge can also be avoided.

In sum, erroneous beliefs can never be valuable, either in the short no in the long run. In the short run, knowledge errors are very costly. In the long run, however, erroneously believing that a positive alternative is negative is costly but the lesser evil than correctly believing it is positive. These knowledge errors with positive knowledge can also be interpreted in a different way. Let us assume that a firm is endowed with knowledge about an alternative that is infinitesimally better than an average alternative. Setting aside the firm's appetite for risk, if it is a non-recurring choice, the firm should choose this alternative. In the long run, however, this knowledge endowment may have a different effect: it will use this knowledge to avoid this alternative because with a longer time horizon, it can be confident to discover an above average alternative. Regardless how the firm acts on positive knowledge – if it acts on it, it will be costly. This is the curse of (positive) knowledge.

## **5. Discussion**

Performance differences across firms are often attributed to differences in knowledge endowments. From a behavioral choice and learning perspective (Cyert and March 1963), the distinction between positive knowledge, knowledge about attractive choices, and negative knowledge, knowledge about unattractive choices, is particularly important (Adner and Levinthal 1992, Teece 1981, 2002). Positive knowledge points firms to attractive choices; negative knowledge is “awareness of what not do or of paths to avoid” (Teece 2002: p. 60). Clearly, both types of knowledge are valuable; indeed, the non-negative value of knowledge is one the fundamental premises of expected utility theory (Savage 1954).

Our experiments with a simple n-armed bandit confirm that both positive and negative knowledge always have a non-negative value in the short-run. Negative knowledge is also valuable in the long run, but, positive knowledge can become a liability and costly in the long-run. A less informed firm might be better off than a firm that is endowed with knowledge about an above average, positive

choice alternative. It is important to note that these costs arise despite the fact that this knowledge is completely accurate, never misleading, or outdated. The negative long-run effects of positive knowledge arise because an endowment with positive knowledge makes the exploration of other, potentially even better alternatives appear less attractive. In other words, while there is an intrinsic value of positive knowledge, i.e., it points the firm to attractive alternatives, this short-run value comes at a cost: the long-run cost of locking a firm to a positive, but suboptimal choice. The stronger a firm's beliefs are, the stronger the negative effect. Thus, even if a knowledge endowment is completely accurate, correctly reflecting the actual value of an alternative, a firm would be better off with less strong beliefs (or pessimistic beliefs that underestimate the payoff).

We also demonstrate that knowing a particular alternative is attractive (positive knowledge) creates a dilemma for firms: If knowledge about a positive alternative makes firms choose it, it will be costly in the long run. If a firm seeks to avoid these costs by using this knowledge to avoid this alternative, it will also be (however less) costly. This is the curse of (positive) knowledge, i.e., if a firm acts on this knowledge by either choosing or avoiding this alternative, they will be worse off than an uninformed firm. Qualitatively, these findings hold for a variety of different choice settings and modeling assumptions, including alternative learning mechanisms, choice rules, and the presence of further sources of explorations. These findings on positive knowledge are reverted or disappear in the absence of any uncertainty when learning is trivial, when one signal is sufficient to form completely accurate beliefs. These findings are also reverted if uncertainty is relatively high, when the variance in the signal exceeds the variance in the values of the alternatives.

Our finding that negative knowledge is unambiguously valuable also resonates with several streams of research. For example, although the term "negative knowledge" is not used explicitly, theories of science (Popper 1959, Kuhn 1962, Lakatos 1976) suggest that that scientific knowledge is generated through falsification and we achieve scientific progress through the accumulation of negative knowledge. In fact, negative findings rather than positive findings constitute the majority of knowledge generated in research and science (Drucker 1963). For example, for each successful drug that ultimately makes it to market, there are 10'000 components that fail (Thomke 2003). It took

Edison 1'000 (unsuccessful) attempts to invent the light bulb. Yet these failed attempts also generated some important knowledge. Some courts have recognized negative knowledge as a trade secret (Graham 2008) and there are calls for “null patents” (Seymore 2011). The problem with this negative knowledge is that it rarely gets disclosed (in science, this phenomenon is called the “file drawer problem” Rosenthal 1979). In the pharmaceutical industry, negative knowledge is considered “the most readily overlooked part of a company’s knowledge assets” (Hodgson 2001). Yet, there is also a growing recognition of the value of negative knowledge. For example, firms like IDEO Product Development, stockpile their knowledge about both successes and failures, “providing a resource that, if not applicable to one set of experiments, can be used for subsequent inquiries” (Thomke 200: p.23). Similarly, prior research has identified entrepreneurial and business failure as important opportunities for learning (e.g., McGrath 1999, Knott and Posen 2005, Hsu 2007). In many cases, failure may imply that the firm never discovered a way to successfully implement its business idea (positive knowledge) but at least learned (the hard way) what does not work (negative knowledge).

Our findings have important implications for several streams of research: First, our analyses shed new light on the discourse about (the relative value of) learning from success and failure (e.g., Madsen and Desai 2010, Starbuck and Hedberg 2001, Edmondson 2011, Kim and Miner 2007)). Knowledge is often the outcome of learning from (own or other’s) experience (Argote and Miron-Spektor 2011): Negative knowledge is generated through learning from failure while positive knowledge is the outcome of learning from success (Teece 2013). Popular management literature and popular wisdom often suggest that “there is more to learn from failures than from success” (Välikangas, Hoegl, and Gibbert 2008). Others suggest there is more to learn from success than from failure (Robischon 2010). An integration of these two perspectives, i.e., systematic evidence about the (relative) value of these two modes of learning is missing. The question of the relative value of learning from success or failure maps directly to our research question about the relative value of positive knowledge acquired through learning from success and negative knowledge acquired through learning from failure. Setting aside any effects of failure and success on aspirations and search (Greve 2003), our study suggests that there is some truth in both positions. We show that under some conditions negative knowledge is more valuable than positive knowledge (and the other way around).

We also uncover the mechanisms through which agents can reap value from positive or negative knowledge and extend our reasoning about the value of such knowledge beyond static, one-shot choice situations.

Second, from a strategic perspective, knowledge is often portrayed as the most important firm asset (Dierickx and Cool, 1989, Grant 1996) and heterogeneity in knowledge bases among firms is the main determinant of sustained competitive advantage and superior firm performance (Decarolis and Deeds 1999, Eisenhardt and Santos 2002). According to the knowledge-based view (Grant 1996), tacit knowledge is the primary source of sustained competitive advantage; specifically, firms that are more efficient in integrating and utilizing their members' (tacit) knowledge should experience performance advantages. If knowledge is regarded as an asset, transferring, utilizing, and converting tacit knowledge into explicit knowledge are the primary challenges for firms (Winter and Szulanski 2001). Our study adopts a different perspective. Consistent with behavioral accounts of firms (Cyert and March 1963), we understand knowledge as an input for organizational choice and learning processes. A firm's knowledge base reflects its beliefs about the attractiveness of various courses of actions. If these beliefs embody truth, we call it knowledge (March 1991). Positive knowledge guides firms to particular choices; its negative knowledge makes it shy away from particular choices. Both positive and negative knowledge generate short-term performance advantages for firms, but these advantages are not necessarily sustainable, even in non-dynamic environments. In the long run, negative knowledge does not confer any performance advantages upon firms, only positive knowledge has the capacity to generate sustainable performance advantages. However, these advantages are only generated through knowledge about particularly attractive choices; knowledge about less attractive but still performance-enhancing choices generates sustainable performance disadvantages. In sum, while the "knowledge-as-an-asset" perspective suggests that identifying, absorbing, and transferring valuable knowledge within the firm can create performance advantages, our study points to some limitations of this logic if we adopt a choice and learning perspective. Thus, sharing best practices (Winter and Szulanski 2001) might be dangerous if it is not indeed the best practice.

Third, and relatedly, while the existing literature highlights the importance of prior or pre-

entry knowledge for subsequent choices (Shane 2000) and, at least implicitly, often assumes positive effects of prior knowledge (Gavetti and Levinthal 2000, Baron and Ensley 2006, Gruber, MacMillan, and Thompson 2008), our study points to the potential downsides of such knowledge. Undisputedly, prior knowledge has important implications for organizational choices: “What an organization knows at its birth will determine what it searches for, what it experiences, and how it interprets what it encounters. While there seems to be universal agreement [that this prior] knowledge strongly influences future learning, many of the rich details of the matter are yet to be investigated” (Huber 1991: p. 91). At least implicitly, this influence of prior knowledge is often considered beneficial, in particular if this knowledge is not erroneous, outdated, or misleading. For example, for interdependent choice problems, Rivkin (2001) demonstrated that more knowledge is always better than less knowledge. Similarly, Gavetti and Levinthal (2000) showed that firms could benefit substantially from holding some unbiased but crude knowledge about the value of (interdependent) choices. As we show, this knowledge can guide firms to attractive sets of choices and prevent them from focusing on unattractive choices. The value of knowledge is always non-negative in these studies while in our study, (positive) knowledge can also take negative values. Yet, even with interdependent choice problems, we would find that some knowledge is positive in the short-run but negative in the long run. Take a firm that has knowledge about the position of the lowest local peak. This peak is still an above average position in the landscape and, as a result, in the short-run, this knowledge will lead to better choices. Yet, in the long run, this knowledge can be negative because it prevents firms to discover better peaks.

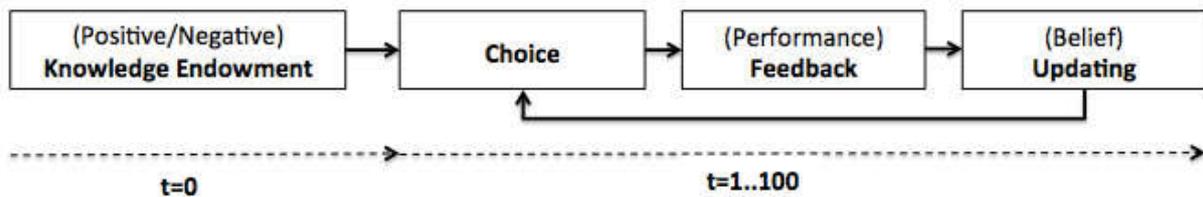
## FIGURES

**Figure 1 The Value of (Positive and Negative) Knowledge in One-Shot Problems**

| Alternative                   | 1    | 2     | 3    | 4    | Avg |
|-------------------------------|------|-------|------|------|-----|
| Payoffs                       | 2.0  | 1.0   | -0.9 | -2.1 | 0.0 |
| Value of Knowing Payoff       | 2.0  | 1.0   | 0.3  | 0.7  | 1.0 |
| Value of Positive Knowledge   | 2.0  | 1.0   |      |      | 1.5 |
| Value of Negative Knowledge   |      |       | 0.3  | 0.7  | 0.5 |
| Expected Value of Exploration | -2/3 | -.1/3 | 0.3  | 0.7  | 0.0 |

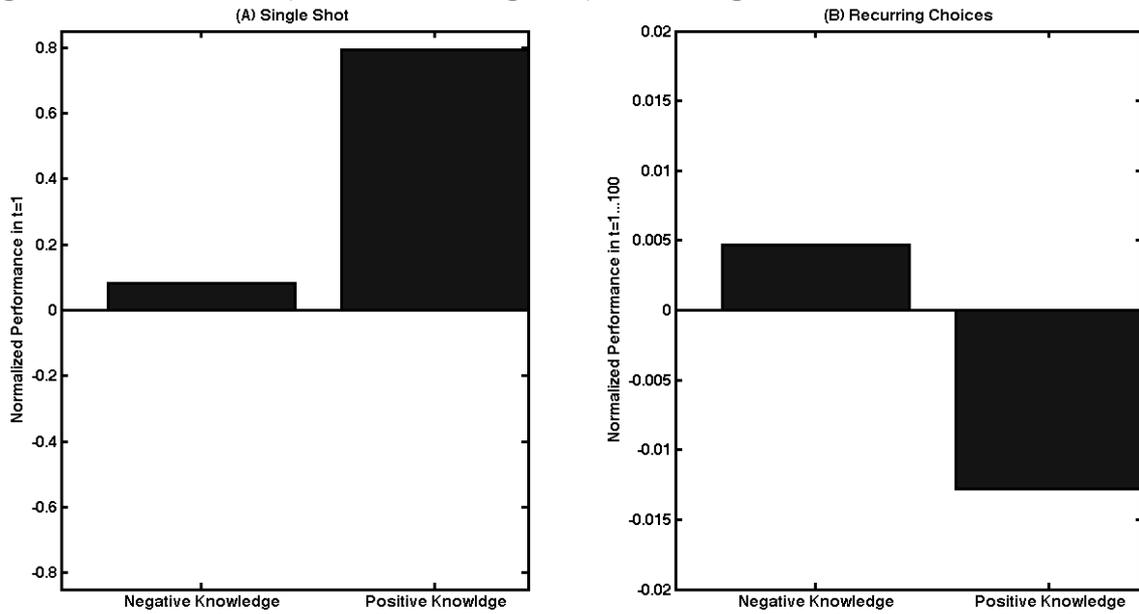
Note: For positive alternatives, the Value of Knowing Payoff equals the alternative's payoff. The Value of Knowing the payoff of a negative alternative is calculated by dividing the average payoff across all choices for which the firm is not endowed with knowledge. For example, for alternative 3, this value equals  $(2.0+1.0-2.1)/3=0.3$ . The Expected Value of Exploration is calculated in the same way (for both positive and negative alternatives). A firm that it is endowed with (positive) knowledge about the 2<sup>nd</sup> best alternative and decides to explore forgoes a payoff of 1.0 and can expect to receive a payoff of -1/3.

**Figure 2 Model of Learning**



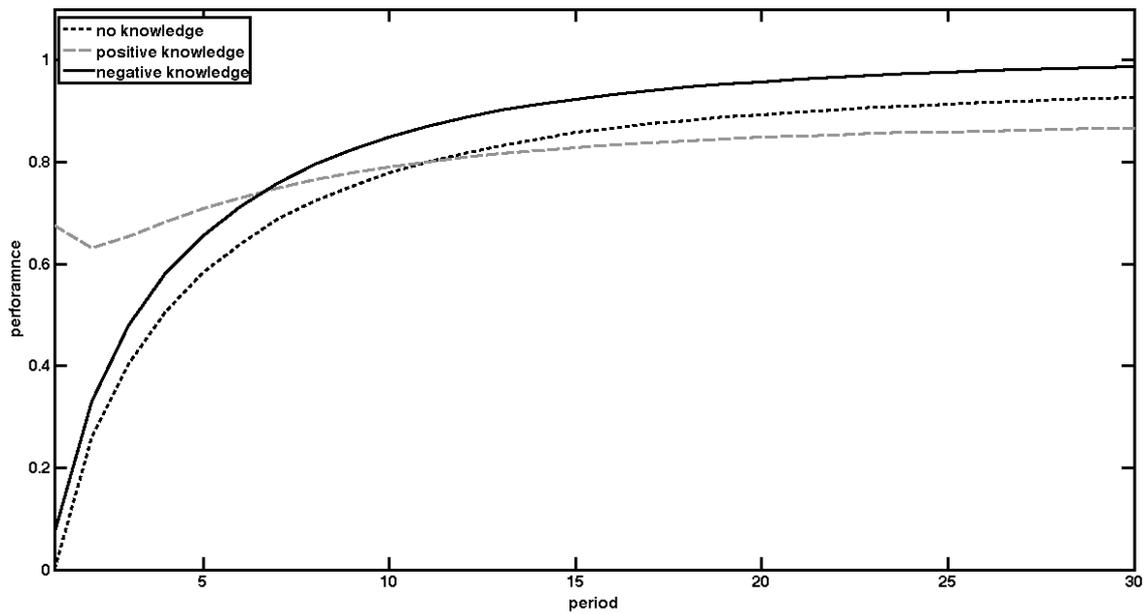
Note: Our model is based on the standard n-armed bandit model (Sutton and Barto 1998). The only deviation from the standard n-armed bandit model is that in  $t=0$ , an agent's beliefs may not always be flat, zero beliefs. Instead, an agent might be endowed with a correct belief (i.e., the belief equals the actual payoff) on one arm. If this arm is associated with a positive knowledge, we call this knowledge endowment "positive knowledge". If this arm is associated with a negative payoff, we call this "negative knowledge".

**Figure 3 The Value of (Positive and Negative) Knowledge**



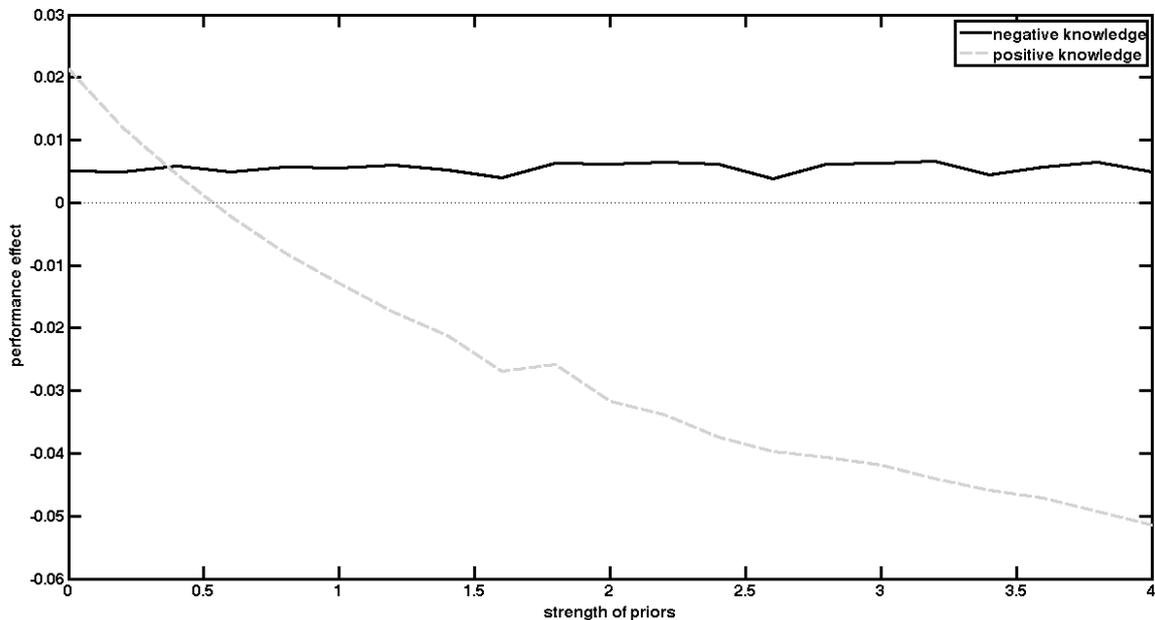
Note: On the y-axis, we report the performance for one-choices (panel A) and repeated choices (panel B, average performance over 100 periods). We normalize performance by subtracting the performance of uninformed choices (i.e., choices without any knowledge endowment). Negative knowledge implies that the agent is endowed with knowledge about the payoff of one (randomly selected) alternative with a negative payoff; positive knowledge implies that the agent is endowed with knowledge about the payoff of one (randomly selected) alternative with a positive payoff.

**Figure 4 The Evolution of the Value of Knowledge**



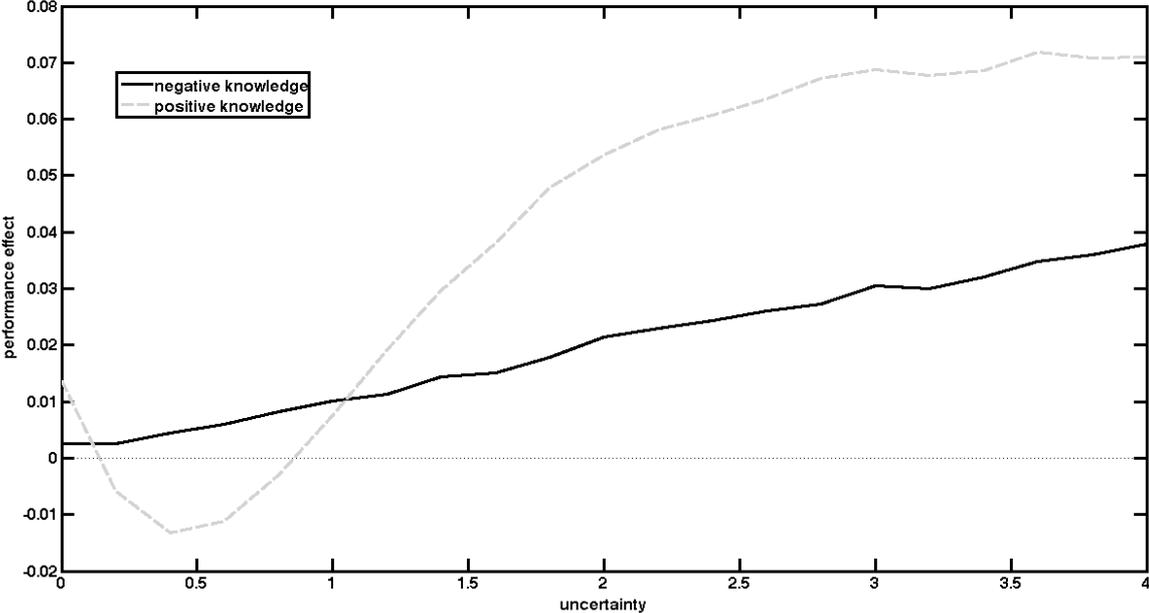
Note: On the y-axis, we report the average performance as a function of time (x-axis). In  $t=0$ , we endow agents with knowledge about no alternative (“no knowledge”), one positive alternative (“positive knowledge”), or one negative alternative (“negative knowledge”).

**Figure 5 The Effect of Strength of Priors on the Value of Knowledge**



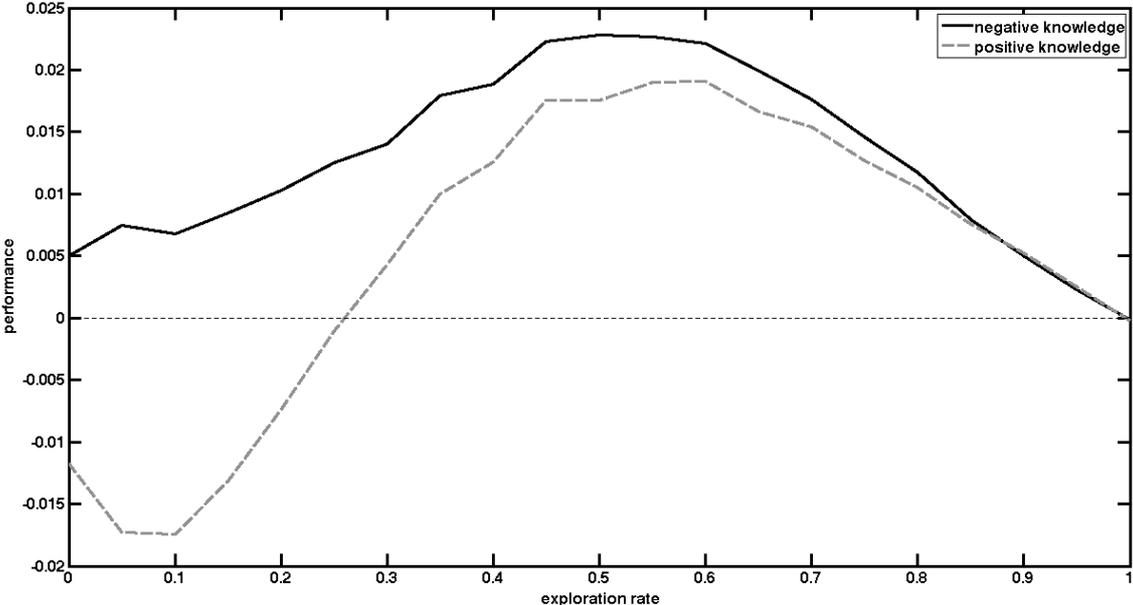
Note: On the y-axis, we report the normalized performance effect of varying the strength of the agent’s initial priors. We normalize performance by first computing the average performance over the first hundred periods and then (2) subtracting the corresponding value of an uninformed choice.

**Figure 6 The Effect of Uncertainty on the Value of Knowledge**



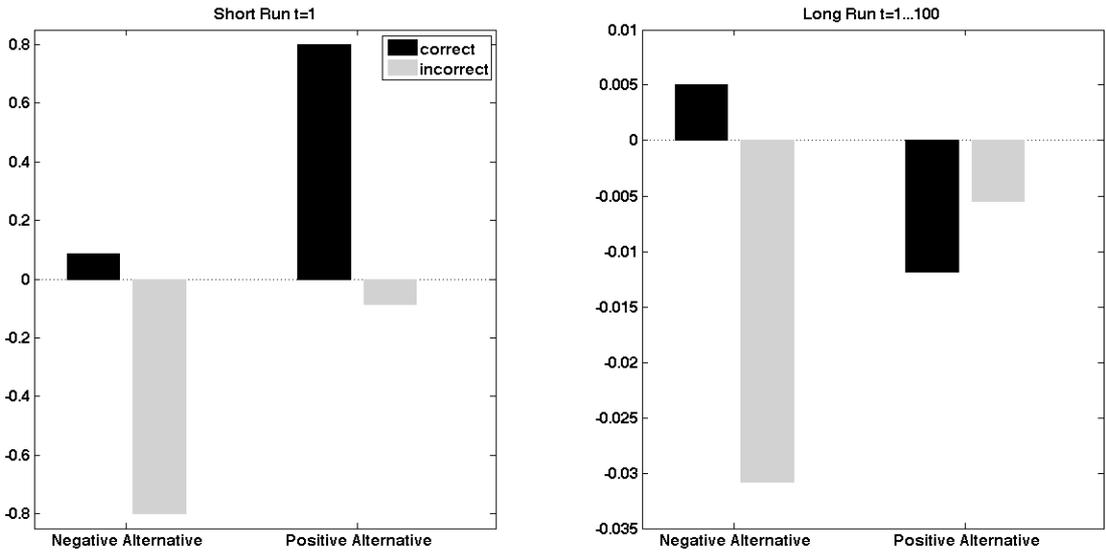
Note: On the y-axis, we report the normalized performance effect of varying the level of uncertainty in the performance feedback. We normalize performance by first computing the average performance over the first hundred periods and then (2) subtracting the corresponding value of a uninformed choice.

**Figure 7 The Effect of Exploration on the Value of Knowledge**



Note: On the y-axis, we report the normalized performance effect of varying the agents' proclivity to explore. We normalize performance by first computing the average performance over the first hundred periods and then (2) subtracting the corresponding value of uninformed choices. Please note: the optimal level of exploration (results on the optimal exploration rate are available from the authors upon request) is around 0.25.

**Figure 8 Knowledge Errors**



Note: The left panel reports the normalized performance for one-shot choices; the right panel reports the normalized performance averaged over the first one hundred periods. The black bars show the performance effect of correct beliefs; the gray bars of incorrect beliefs. A correct belief about a negative alternative implies that the agent’s initial belief corresponds to the (negative) payoff of this alternative; an incorrect belief reverses the sign of the belief. The belief on a positive alternative becomes negative and the other way around.

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