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When higher productivity hurts: The interaction between overconfidence and capital☆

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ABSTRACT

We investigate how the increased availability of a factor of production can make an overconfident agent worse off. In our model, two effects drive this result. First, when a production factor and ability are complements in the production function, the agent may overpay for the production factor. Second, the acquisition of this factor will distort the agent's choice of what activities to pursue. In contrast, when the factor and ability are substitutes, the agent will undervalue the factor. In a laboratory experiment we find that subjects overpay for ability-complements, and underpay for ability-substitutes. Subjects provided with free ability-complements earn less due to how it distorts the subjects' perceptions of what activity to pursue.

1. Introduction

Much research has shown that overconfidence[1] is widespread (Kruger and Dunning, 1999) and has an important effect on many economic outcomes (Barber and Odean, 2000; Malmendier and Tate, 2005; Koellinger et al., 2007; Malmendier and Tate, 2008; Ederer and Manso, 2013; Herz et al., 2014). However, little is known about how overconfidence interacts with the economic environment. How do the welfare implications of overconfidence vary with an increase in a production factor? In this paper we show that having access to more of a factor can lead overconfident agents to strictly worse outcomes. Two effects drive this result. First, an overconfident agent may overpay for the factor, and second, an increase in the factor can magnify the disparity between people's expected performance and actual performance, thereby increasing excess entry into activities that require high performance (in the spirit of Camerer and Lovallo, 1999). We demonstrate this result both theoretically and in a laboratory experiment. These effects carry substantial implications in numerous real-world domains.

Consider, for example, the typical decision problem faced by a financially unsophisticated investor. The investor may consider a passive strategy consisting of holding well-diversified index funds, or an active strategy that requires picking individual stocks. The active strategy requires greater knowledge, but the market offers many resources to acquire knowledge, including prospectuses, news articles, books, courses, and investor newsletters, amongst other resources.

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[1] Moore and Healy (2008) make the distinction between three forms of overconfidence. *Overestimation* occurs when individuals systematically believe their performance to be better than it actually is, *overplacement* occurs when individuals believe they are higher ranked in performance relative to some population of agents, and *overprecision* occurs when people believe that their judgments are more accurate than they are. In both the model and experiment, the paper is concerned only with overestimation.

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An overconfident investor may overestimate his capacity to effectively use this knowledge.[2] Several studies find a negative relationship between investor information and portfolio performance. Survey data on Italian (Guiso and Jappelli, 2006) and Portuguese investors (Abreu and Mendes, 2012) show that overconfident investors are more likely to acquire knowledge about stocks, trade more frequently and achieve lower risk-adjusted returns on their portfolios. Huber et al. (2008) find that more information in an experimental lab asset market is not always associated with better returns. In a similar vein, Barber and Odean (2002) document an increase in trading activity when retail investors switch from phone to more information-rich online trading platforms. While investors in their sample initially beat the market on average by over 2% annually, after switching to online investing they underperformed by 3% annually. In all of these examples, increased information and ability to trade seem to make investors worse off. The authors' interpretation is that the greater access to information and greater autonomy inherent in the online platform led to increased overconfidence among investors.

Firms may exploit this phenomenon of greater information leading to greater excess entry. Casinos in Las Vegas sell blackjack strategy cards and allow players to use them at the tables. Players may enter the game expecting to follow the strategy with near precision but err too often. Following the strategy is by no means trivial. Griffin (1991) finds that typical blackjack play has an error rate that gives the house an additional advantage of 1.41 percentage points above the strategy depicted on the card. Although strategy cards may improve play, gamblers may think they can follow the strategy better than they actually can. This would encourage more frequent and intense gambling that could ultimately lead to greater financial loss for the gambler.

Perhaps the consequences of overconfidence are greatest in the decision to go to war. WWI is a case in point (Johnson, 2004). Germany's war strategy, known as the Schlieffen Plan, depended critically on a quick victory over France so that troops could be raced to the eastern front to defend against a slow but large Russian army. German engineers constructed strategic military railways at the end of the 19th century and based their military strategy firmly on the presumption that this new technological advance would provide the speed necessary for the Schlieffen Plan to succeed (Tuchman, 1962). While addressing German troops prior to battle in August 1914, Kaiser Wilhelm II declared, “You will be home before the leaves have fallen from the trees” (Stoessinger, 1987). Perhaps under superb command the Kaiser's assessment would have been accurate. However the leadership ability needed to successfully implement the Shlieffen Plan may have been exceedingly high. Instead the war lasted over 4 years and cost over 7 million German casualties. The technological and infrastructural advances prior to the war may have been a critical factor that induced German attack.

In each of these examples (investing, gambling, conflict), there is an acquisition of a production factor, which we will simply refer to as capital, that increases output (knowledge about stocks or stock-picking strategies, blackjack strategy card, new technology and infrastructure), and an exogenous ability (ability to interpret stock charts and apply strategy, ability to remember and implement rules, military leadership and acumen).[3] In each of these examples, the capital appears to be a complement to ability: data about stocks is useless if one cannot interpret it, a strategy card does little good if one cannot implement the rules quickly, military railways will not help a German general win the war unless he has the acumen to defeat France quickly. This acquisition of capital increases overestimation of output, which induces pathological entry (active investing, more gambling, war).[4] The unintuitive result that increasing a production factor can *decrease* welfare follows from the logic of a simple model. Suppose production is a function of ability and capital, where ability is exogenous and where capital is to be interpreted very broadly as any endogenously chosen factor that increases production.[5] If ability and capital are complements in the production function, then an agent's overestimation of his ability causes him to overvalue capital. Thus the agent will overpay for capital. Furthermore, because the agent overestimates his ability, an increase in capital increases his overestimate of output. Access to this capital may further make the agent worse off because it results in an excessive purchase of capital that then magnifies the agent's bias in his estimate of his output. This bias can lead to any number of poor decisions such as pathological entry in active investing, gambling, or military engagements.

Not all forms of capital are overvalued and induce greater bias in overconfident agents. If ability and capital are substitutes in the production function, these results are reversed. Acquiring an ability-substitute decreases an overconfident agent's overestimate of his productivity. Although the ability-substitute reduces bias, the agent will generally undervalue this type of capital and often purchase too little of it. Indeed, Bhattacharya et al. (2012) study investors at a brokerage firm who were offered free financial advice. Less than 5% of investors obtained the advice and even fewer followed it despite the fact that following it would have improved portfolio performance.

In the next section we present a formal model of this framework. We show that capital that is a complement with ability can make agents worse off but capital that is a substitute with ability will often make agents better off. We then provide a proof-of-concept in a laboratory experiment. Subjects begin the experiment by answering a 10-question multiple-choice trivia quiz. Subjects are paid $2.50 for every question they answered correctly. After subjects answer each question we elicit their belief that they answered the question correctly in an incentive-compatible manner. The trivia quiz was very difficult and, consistent with previous work (Moore and Healy, 2008; Grieco and Hogarth, 2009), subjects overestimate their score by 2.871 questions on average (or 174% above their actual score), indicating widespread overconfidence in ability.

In the second and third stage subjects are again paid $2.50 for each question they answer correctly on a second quiz but can now purchase one of two types of capital to improve their

[2] Although some active investors do beat the market, the majority do substantially worse. Barber et al. (2009) show that 2.8% of all Taiwanese personal income is lost in the Taiwanese stock market due to overly aggressive trades. On average, each stock sold by an individual investor does worse than a stock purchased. This represents a huge redistribution of 2.2% of Taiwanese GDP from overconfident individual investors to institutional investors.

[3] Modeling knowledge as a production factor has a long tradition in economics. Technological knowledge is a factor in a representative firm's production function in several growth models (Romer, 2011), knowledge as the product of education is modeled as human capital in a firm's production function (Becker, 1962), and more recently, knowledge in the form of financial literacy is modeled as a factor in a consumer's production function to generate higher returns through better financial decisions (Lusardi, Michaud, and Mitchell, 2011).

[4] In some models, excess entry is caused by overplacement, as in Camerer and Lovallo (1999). In this context, the the market for the ability-based activity has a finite capacity and the optimality of entry is based not on productivity, but the ranking of productivity amongst the other entrants. In this paper, we are considering suboptimal entry from overestimation. As long as the payoff after entry is determined to some extent by absolute productivity (as it often is), and not only productivity ranking, then overestimation may also cause suboptimal entry.

[5] We use this very broad interpretation because the distinction between capital and other production factors is not necessary for the purposes of this paper. We use the term capital to potentially refer to all production factors. Thus knowledge, effort, and even potentially labor are all to be interpreted as capital, at least for the purposes of this paper, as well as the more traditionally-interpreted forms such as financial resources, machines, tools, buildings, and learnable skills.

performance. First subjects are offered capital in the form of four extra questions. Extra questions are an ability-complement because the higher the subject's ability at trivia, the more valuable each additional quiz question. Next subjects are offered the chance to purchase insurance, an ability-substitute. The insurance awards subjects the equivalent of 0.4 extra correct questions for each question that they answer incorrectly. The more skilled the subject is at trivia, the less valuable the insurance. We elicit subjects' willingness to pay (WTP) for each form of capital. As predicted by theory, we find that subjects overvalue the ability-complement and undervalue the ability-substitute.

Like an investor who can choose to invest in passive index funds or take a skill-dependent active trading strategy, in the final stage subjects choose to earn either random pay or performance pay based on their second quiz score. Subjects make this decision under three conditions: no additional capital, four bonus questions, and insurance. We find that the bonus questions increase excess entry into performance pay and consequently dramatically reduce subjects' earnings relative to the control condition (no additional capital). In contrast, when subjects have the insurance they earn significantly more than in the control. This demonstrates a proof of concept that productivity-enhancing ability-complements can make an agent worse off. Although earlier work in psychology has demonstrated that the provision of information may increase overprecision (Oskamp, 1965; Peterson and Pitz, 1988; Tsai et al., 2008) — the relationship between overconfidence to production has been unexplored.

We view the contribution of the paper as threefold. First, we make the conceptual distinction between production in which ability and capital are complements and those in which they are substitutes. This is an important distinction which provides a way to determine when capital is likely to make overconfident agents better or worse off. Second, we show theoretically how outcomes for overconfident agents can be made worse by complements and mitigated by substitutes. Third, we demonstrate a proof of concept that complements can make overconfident agents worse off in a controlled laboratory environment.

2. Model

2.1. Setup

The agent has ability θ and perceives his ability to be $\hat{\theta} > \theta$. The agent has a unit budget of activity which can be allocated continuously between two activities. The first activity depends on ability. Output in this activity is given by the single-output production function $y(k, \theta)$, where $k \in \{0, 1\}$ is capital. Capital is interpreted as any endogenously chosen item that increases production: education, financial resources, machines, tools, physical buildings, tacit skills, etc. Capital increases output $y(1, \theta) > y(0, \theta)$, and output is increasing in ability $\frac{\partial y(k,\theta)}{\partial \theta} > 0$. Let p be the price of capital. The agent may allocate toward the ability independent activity, $e \in [0, 1]$.

The second activity is ability-independent and yields output given by $f(1-e)$. This task can be interpreted as all the other activities that the agent may wish to engage in, such as other market-based labor, home production, and leisure. We assume $f(\cdot) > 0$, $f'(\cdot) < 0$, and $f''(\cdot) > 0$. As a technical assumption to produce interior solutions and unambiguous comparative statics we assume the Inada conditions, $\lim_{x\to 0} f'(x) = \infty$ and $f'(1) = 0$. The term $f(1-e)$ is the opportunity cost of engaging in the ability-dependent activity. We take a risk-neutral formulation to neatly characterize the basic principle.[6]

[6] Risk aversion will change the generality of the theoretical predictions, since behavior will depend on the curvature of the utility function as well as the sources of risk. In Section 4.5 we show that the prediction, in the context of our experiment, is robust to risk aversion.

Utility is given by

$$u(k, e, \theta) \equiv e \cdot y(k, \theta) - pk + f(1-e). \tag{1}$$

However, the agent misperceives his ability. Thus he instead maximizes his perceived utility,

$$u(k, e, \hat{\theta}) = e \cdot y(k, \hat{\theta}) - pk + f(1-e). \tag{2}$$

Capital and ability may be complements or substitutes in the production function.

Definition. Capital is an *ability-complement* if $\frac{\partial y(1,\theta)}{\partial \theta} \geq \frac{\partial y(0,\theta)}{\partial \theta}$. It is a *strict ability-complement* if the inequality is strict.

Definition. Capital is an *ability-substitute* if $\frac{\partial y(1,\theta)}{\partial \theta} \leq \frac{\partial y(0,\theta)}{\partial \theta}$. It is a *strict ability-substitute* if the inequality is strict.

2.2. Solution

We now find the maximum the agent is willing to pay to obtain the unit of capital. The agent chooses activity allocation e such that $f'(1-e) = y(k, \hat{\theta})$. Therefore, the agent's optimal allocation is a function of capital and perceived ability: $e(k, \hat{\theta}) = 1 - f'^{-1}(y(k, \hat{\theta}))$.

Definition. There is *excess entry* with capital k when the allocation to the ability-dependent activity exceeds the optimal amount $e > e(k, \theta)$.

Perceived utility with the capital less the payment will be $e(1, \hat{\theta}) \cdot y(1, \hat{\theta}) + f(1 - e(1, \hat{\theta}))$. Perceived utility without the capital is $e(0, \hat{\theta}) \cdot y(0, \hat{\theta}) + f(1 - e(0, \hat{\theta}))$. The agent's reservation price is then

$$\begin{aligned}\bar{p}(\hat{\theta}) &= e(1, \hat{\theta}) \cdot y(1, \hat{\theta}) + f(1 - e(1, \hat{\theta})) \\ &\quad -\left[e(0, \hat{\theta}) \cdot y(0, \hat{\theta}) + f(1 - e(0, \hat{\theta}))\right]\end{aligned} \tag{3}$$

However the agent's optimal reservation price is

$$\begin{aligned}\bar{p}(\theta) &= e(1, \theta) \cdot y(1, \theta) + f(1 - e(1, \theta)) \\ &\quad -\left[e(0, \theta) \cdot y(0, \theta) + f(1 - e(0, \theta))\right]\end{aligned} \tag{4}$$

Proposition 1 (Overpayment for ability-complement)**.** *The reservation price for an ability-complement, and activity allocation e is strictly increasing in $\hat{\theta}$.*

All proofs are in Appendix A. An overconfident agent believes that the capital will improve output more than it actually does. The agent also perceives that optimal allocation e is greater than what is truly optimal. Both factors cause overestimation of the value of capital. For example, an overconfident investor will overpay to take a complicated course on active trading both because he overestimates how effectively he could implement the strategies he learns in the course, and because he believes he should spend more time and resources actively trading than the true optimum.

A similar logic suggests an opposite effect for an ability-substitute.

Lemma 1 (Underpayment for an ability-substitute and fixed e)**.** *Given a fixed activity allocation, the reservation price for an ability-substitute is monotonically decreasing in $\hat{\theta}$. The reservation price is strictly decreasing in $\hat{\theta}$ for strict ability-substitutes.*

This states that if activity allocation is exogenously fixed, the agent will always undervalue the ability-substitute. The agent will not necessarily undervalue the ability-substitute if activity allocation is chosen contemporaneously or after the ability-substitute has been purchased. The agent underestimates how much the ability-substitute increases output and this causes underestimation for the value of the capital. However the agent is also overconfident and will excessively enter, which causes overestimation for the value of the capital. It is only when the former effect dominates that the agent will undervalue the ability-substitute.

Proposition 2 (General underpayment)**.** *The reservation price for capital is strictly decreasing in $\hat{\theta}$ if and only if $\frac{\partial y(0,\hat{\theta})/\partial\hat{\theta}}{\partial y(1,\hat{\theta})/\partial\hat{\theta}} > \frac{1-f'^{-1}(y(1,\hat{\theta}))}{1-f'^{-1}(y(0,\hat{\theta}))}$.*

Proposition 2 states that as long as the additional allocation e induced by the ability-substitute is sufficiently small, it will be undervalued. For example, an overconfident investor may underpay for a remedial course on "Introduction to Basic Investing" because he believes he will learn less from it than he actually will. Being an ability-substitute is a necessary but not sufficient condition for undervaluation.

The misvaluation of capital can lead to significant welfare loss but perhaps the more egregious error is the induced excess entry. Although overconfidence on its own will lead to excess entry, the acquisition of additional capital may increase or decrease this excess entry. Ultimately, the provision of capital may make the agent worse off. Consider two regimes, one in which capital is unavailable and the other in which capital is provided for free. If the capital is an ability-substitute, then its provision will always increase utility. This is because (1) it increases productivity, and (2) it reduces the agent's misperception of his productivity, $y(1,\hat{\theta}) - y(1,\theta) < y(0,\hat{\theta}) - y(0,\theta)$. The fact that $f''(\cdot) < 0$ implies that excess entry will be reduced, and the fact that $f'''(\cdot) > 0$ implies the welfare loss from excess entry will be reduced as well.

Lemma 2. *The free provision of an ability-substitute increases utility.*

If the condition of Proposition 2 is satisfied, then from Lemma 2 the opportunity to purchase the ability-substitute at *any* arbitrary price will make the agent better off. This is because the agent will not err by overpaying for the ability-substitute and the agent's deadweight loss from excess entry will not increase. So providing our hypothetical investor the opportunity to purchase "Introduction to Basic Investing" cannot hurt him.

In contrast, the ability-complement will have the direct effect of increasing productivity and the indirect effect of increasing excess entry. The key message in Proposition 3 below is that an overconfident agent can be made *worse off* through the provision of an ability-complement.

Proposition 3 (Increasing the price of capital may increase welfare)**.** *Utility is monotonically decreasing in the price of capital if and only if $\frac{y(1,\hat{\theta})-y(1,\theta)}{y(0,\hat{\theta})-y(0,\theta)} < \frac{1-f'^{-1}(y(0,\hat{\theta}))}{1-f'^{-1}(y(1,\hat{\theta}))}$. This implies that utility is not monotonically decreasing in the price of an ability-complement.*

Proposition 3 states that for some prices utility is increasing in the price of an ability-complement. This means increasing access to an ability-complement may make an agent worse off. This is coming from two effects. First the agent will overpay for the ability-complement, and second the ability-complement will increase the deadweight loss of excess entry. It is easy to construct examples where even the free provision of an ability-complement reduces welfare due to the effect of increased excess entry. Decreasing the price of an ability-substitute could make an agent worse off as well if the increase in excess entry is sufficiently large. The implication is that the agent may be better off when the price of capital is prohibitively costly. Our illustrative investor may be better off when the course on active trading is prohibitively expensive since if the course were more affordable he would overpay for it and it would then inspire greater trading activity leading to greater loss.

3. Experimental design

3.1. Design and hypotheses

The experiment is separated into four different stages: the Confidence Stage, Buy-Capital (ability-complement and ability-substitute) Stages and Entry Stage (Fig. 1). Subjects are informed that their final income will be based on a single decision made in one of the four stages. At the end of the experiment the computer randomly selects one of the four stages to count, selecting any stage with equal chance, and then randomly selects one of the decisions within the selected stage to count, assigning each decision equal probability. Cox et al. (2014) show that this type of payment mechanism effectively elicits subjects' true preferences for each decision by limiting the influence of confounding factors such as wealth effects and cross-task contamination.

Confidence Stage: This stage establishes subjects' baseline ability θ and subjects' beliefs about their ability $\hat{\theta}$. Subjects answer a 10-question multiple-choice trivia quiz, labeled "Quiz-A" and are told that they will earn $2.50 for each question they answer correctly. Following each trivia question, subjects are presented with a multiple-price-list (MPL) that asks them to choose between Option A, a $10 payment if they answered the previous question correctly, or Option B, a lottery that pays $10 with probability p and $0 with probability $1-p$. On the first selection $p=0$, and on each subsequent selection, p increases by 5% until it reaches 100%. Subjects then answer, "I choose A for selections 1 through___. For all other selections I choose B. *Enter 0 if you do not want to choose A for any of the selections.*" These questions elicit subjects' beliefs that they answered the question correctly. It is incentive compatible to state the selection with the highest probability that is below one's belief that the question was answered correctly. The experimental instructions are in Appendix B. This "cutoff" p gives a lower bound for one's belief that they answered the question correctly. The sum of these lower bounds over the ten questions gives the subject's incentive-compatible expectation for their quiz score.

In addition we obtain a simpler no-stakes elicitation of confidence. At the end of the Confidence Stage, we ask "How many of the previous 10 questions do you think you answered correctly?", and "You will soon take another similar 10-question quiz of roughly the same difficulty. How many questions do you think you will answer correctly?" These questions have the advantage of being very easy to understand, but the disadvantage of not having incentives for truth-telling.

Subjects do not receive any information about their actual score at any point prior to the end of the experiment. We use trivia questions as the performance task because effort plays little role – a person either knows the answer or does not (there is no computation or deduction required) – and because previous research (Moore and Healy, 2008; Grieco and Hogarth, 2009) shows that difficult quiz questions reliably generate overconfidence. We select particularly difficult trivia questions to increase the likelihood that a large portion of our sample would exhibit overconfidence. To reduce the confounding effect of differences in difficulty between the quizzes we randomize the order in which the questions are presented. Subjects are randomly assigned one of five different question orderings. These five different orders and the process by which the orders are generated are discussed in Appendix C.

Buy-Capital Stages: The purpose of these stages is to identify the subjects' willingness-to-pay (WTP) for ability-complements and ability-substitutes. Subjects are informed that they will take another quiz, labeled Quiz B, that is similar in difficulty and content to Quiz A. Consistent with the Confidence Stage, subjects again receive $2.50 for each question they answer correctly on Quiz B. However, now they can increase their earnings by acquiring extra questions in the Ability-Complement Stage and an insurance policy

	Tasks	*Earnings*
Confidence Stage	1. Quiz A. 2. Elicitation of beliefs in Quiz A performance.	1. $2.50 per correct answer on Quiz A. 2. Choose $10 for a correct answer on question i or a lottery that pays $10 with probabability p.
Ability-Complement Stage	3. WTP for extra questions (ability-complement) on Quiz B.	3. $2.50 per correct answer on Quiz B.
Ability-Substitute Stage	4. WTP for insurance (ability-substitute) on Quiz B.	4. $2.50 per correct answer on Quiz B, $1.00 for each incorrect answer.
Entry Stage	5. Choose earnings based on Quiz B performance OR random earnings that are independent of performance. Choose under conditions *no cap ital, extra questions* and *insurance*.	5. Payment based on performance (see Appendix B.8.1) OR $20 or $12 with equal chance.
-	6. Complete Quiz B.	-

Fig. 1. Experiment order.

in the Ability-Substitute Stage.[7] This is a within-subject design, so each person participates in both the Ability-Complement and Ability-Substitute Stages. In the Ability-Complement Stage the subject has the opportunity to acquire four extra questions. The extra questions are an ability-complement since they weakly increase earnings and the magnitude of this increase is increasing in the quiz taker's ability. With insurance the subject earns $1 for each incorrect response. This is an ability-substitute since it weakly increases earnings and the magnitude of this increase is decreasing in the quiz taker's ability. As Propositions 1 and 2 suggest, we hypothesize subjects will overpay for the ability-complement and underpay for the ability-substitute.

Subjects may purchase these forms of capital for the subsequent Quiz B. We use a multiple-price list (MPL) to elicit each subject's incentive-compatible valuations for the ability-complement and the ability-substitute. The MPL asks subjects to make a series of choices between a fixed payment $\$x$ and the capital for Quiz B. On the first selection $x = 0$ and on each subsequent selection x increases by 50 cents until it reaches $10. The highest value of x for which the subject chooses the capital is an upper bound for the subject's WTP.

In this stage entry is fixed. Propositions 1 and Lemma 1 lead us to the following hypotheses.

Hypothesis 1. If the population is overconfident on average, then average WTP for the ability-complement will be greater than its average true value.

Hypothesis 2. If the population is overconfident on average, then average WTP for the ability-substitute will be less than its average true value.

[7] The order of the Ability-Complement Stage and the Ability-Substitute Stage was randomized so that 74 out of 152 subjects completed the Ability-Complement Stage first.

A direct test of Proposition 1 and Lemma 1 relates variation in beliefs to variation in WTP.

Hypothesis 3. The WTP for the ability-complement should be increasing in a person's belief about their performance.

Hypothesis 4. The WTP for the ability-substitute should be decreasing in a person's belief about their performance.

Entry Stage: In this stage subjects must make an entry decision e to receive income based on random earnings that are not performance dependent i.e. $f(\cdot)$, or performance earnings $y(k, \theta)$. To keep the design easily comprehensible to our subjects, we opted to make e a binary entry decision rather than a continuous allocation. When subjects choose random earnings they receive payment based on a binary lottery that pays $12 or $20 with equal chance. Hence, by selecting random earnings a subject can expect to make $16 on average, regardless of how they perform on Quiz B. When a subject selects performance earnings, payment is determined by how many Quiz B questions they answer correctly. This choice is analogous to an investor's choice between investing in the S&P 500, which is risky but skill-independent, and adopting an active trading strategy that depends heavily on the investor's skill. We characterize excess entry as entering and earning less than $16.

We use a within-subject design, in which each subject decides whether to get performance earnings or random earnings in each of three separate conditions. Each condition has an equal chance of being selected to count for earnings. In the first two conditions, subjects receive $6 plus $2 for each question they answer correctly on Quiz B. In the first condition, the control, subjects get a 10-question multiple-choice quiz. In the second condition, subjects receive the ability-complement, four extra questions in addition to the standard 10-question quiz. In the third condition, subjects receive the ability-substitute, insurance: subjects receive $14 plus $1.20 for each of the 10 questions they answer correctly on Quiz

B.[8] As Proposition 3 suggests, we hypothesize the opportunity to purchase extra questions will make subjects worse off by increasing excess entry, but the opportunity to purchase insurance will not.

Hypothesis 5. If the population is overconfident on average, then average earnings in the Entry Stage will be lower in the ability-complement condition than in the control condition.

Hypothesis 6. If the population is overconfident on average, then average earnings in the Entry Stage will not be lower in the ability-substitute condition than in the control condition.

As a variant of these two predictions one can also administer a stronger statistical test, whether the degree of change in earnings from obtaining capital is correlated with overconfidence. Define the change in earnings from having capital (ability-complement or -substitute) as $\Delta(capital) = earnings(capital) - earnings(control)$.

Hypothesis 7. The change in earnings from the ability-complement is decreasing in overconfidence.

Hypothesis 8. The change in earnings from the ability-substitute is increasing in overconfidence.

Once subjects finish the Entry Stage, they go on to answer the Quiz B trivia questions. Upon finishing Quiz B, they complete a brief survey, stating their college major and gender. The final screen tells subjects how much they earned and which stage was selected to calculate their income.

To ensure subjects understand the instructions, they have to pass several comprehension tests throughout the experiment. Before the Confidence Stage, subjects are required to provide the optimal response to two different practice MPL tasks and can not continue until they answer correctly. On the first practice task subjects are given a MPL to purchase a t-shirt and are told to choose the optimal response if they value the t-shirt at exactly $ 5.25. On the second practice task subjects are given a MPL for which Column A pays out "$10 if it rains tomorrow, and $0 if it does not rain tomorrow" and Column B pays out $10 with probability p. For each selection p increases by 5% from 0% to 100%. Subjects have to choose the response that maximizes their earnings if the chance of rain tomorrow equals 64%. In both the Ability-Complement Stage and the Ability-Substitute Stage we test subjects on the hypothetical value of bonus questions and insurance given specific Quiz B scores. The Entry Stage asks subjects to calculate hypothetical earnings under the three different schemes given specific Quiz B scores. Subjects are required to provide correct answers before continuing. All subjects passed all comprehension tests.

In summary, the Confidence Stage is used to measure θ and $\hat{\theta}$, which represent the subject's ability to correctly answer the trivia quiz and the subject's perception of his or her ability. The Ability-Complement and Ability-Substitute Stages are used to measure subjects' valuations for capital in order to conduct an operationalized test of Proposition 1 and Lemma 1. The Entry-Stage is used to observe subjects' choices to allocate their activity between the ability-dependent and ability-independent tasks, e, and test our operationalization of Proposition 3. Proposition 3 states that a decrease in the price of an ability-complement can make an agent worse off. In the Entry Stage this is represented in an extreme way. Entry under the no-capital condition is equivalent to allocating activity when the price of capital is prohibitively high (i.e. expenditure exceeds the budget). Entry in the other conditions is equivalent to allocating activity when the respective capital is free. In this stage we can observe whether the free provision of the ability-complement reduces subjects' earnings.

[8] Note that the performance payments for correct responses differ from those offered in the previous two Stages. The purpose was to calibrate payments in such a way that earnings from this stage would not be too low.

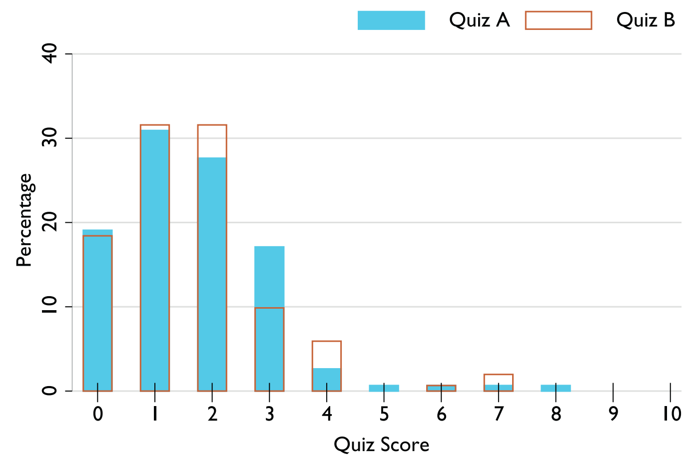


Fig. 2. Distribution of Quiz Scores.

3.2. Sample

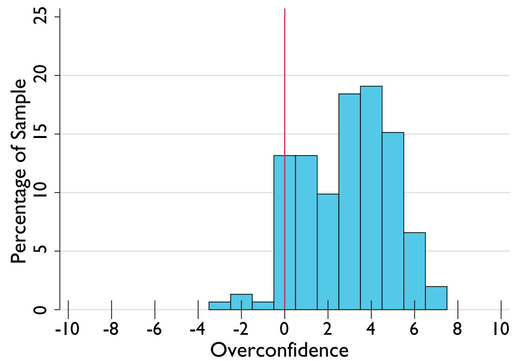
The experiment was conducted at UC Irvine's Experimental Social Science Laboratory (ESSL). Participants were recruited by email from a database of volunteers who expressed interest in participating in experiments. All participants are students at UC Irvine. Our sample consists of 152 subjects who participated over a total of 6 different sessions. The sessions were run on 1/28/14 (1 session), 2/4/14 (3 sessions), 10/16/15 (2 sessions). In the first 4 sessions subjects received $ 5 for participation in addition to their earnings. Due to a change in lab policy subjects were paid $7 for participation for the last 2 sessions on 10/16/15. The number of participants in each session ranged from 19 to 31. The experiment took approximately 25–40 min and was conducted using Qualtrics, a survey system that operates through a web-browser. Each computer station had privacy partitions and subjects were monitored throughout the experiment to limit the chances of cheating. During the experiment, the browser was made full-screen and subjects were instructed not to navigate away nor open or close any software applications. The average payment was $16.97 per subject.

4. Results

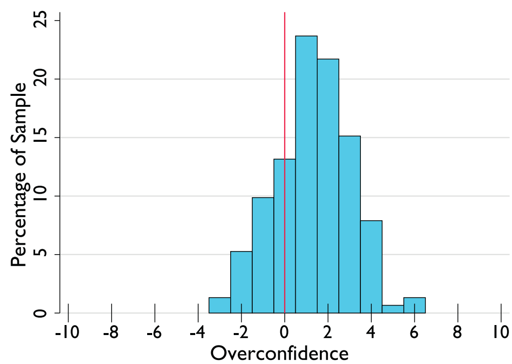
4.1. Overconfidence

The mean score on Quiz A is 1.651 points (SD = 1.343) and the mean score on Quiz B, not including the bonus questions, is 1.658 points (SD = 1.372). The distributions are plotted in Fig. 2. Given that there are five choices provided, a person choosing at random would be expected to get 2 correct on average. The quiz was so hard that people did worse than choosing at random. Nonetheless the Pearson correlation between the two scores is 0.298 and is significant at $p<0.001$, so it does seem that there is an ability component that is stable and persists across exams. The fraction correct over all 24 questions × 152 subjects was only 16.37%.

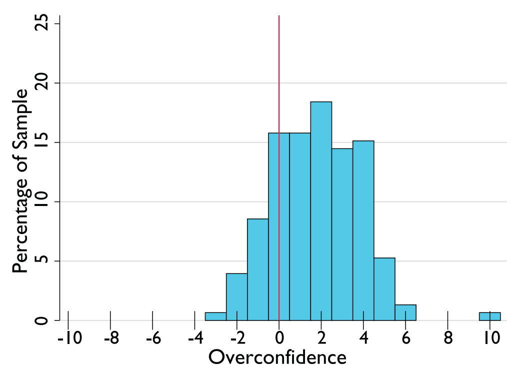
Despite these low scores, the elicited mean belief for Quiz A performance is 4.522 points (SD = 1.755). This is 2.871 points (SD = 2.029) above the true mean, more than double subjects' actual scores and reflects highly significant overconfidence (two-sided paired t-test, $p < 0.0001$). Using the unincentivized method of asking subjects to state their belief about their past performance, on average subjects state they correctly answered 2.961 (SD = 1.631) questions (two-sided paired t-test against the true score, p



(a) IC Overconfidence for Quiz A



(b) Non-IC Overconfidence for Quiz A



(c) Non-IC Overconfidence for Quiz B

Fig. 3. Distribution of overconfidence.
Overconfidence is measured as OC = expected score − actual score. The bars represent bins centered on integer values and have a width of 1. Values on the boundaries are sorted into the higher bin. For example, the bar centered on 0 includes all values greater than or equal to −0.5 and less than 0.5.

$<$ 0.001). Curiously, when asked how many they expect to answer correctly on the next quiz they state 3.447 (SD = 1.698), substantially more than on the previous quiz (two-sided paired t-test, $p < 0.001$). This is also much higher than the actual performance on the second quiz, overestimating their scores by 1.789 (two-sided paired t-test, $p < 0.001$).

Although these measures of confidence differ, they all suggest highly significant and substantial overconfidence. Fig. 3 plots the distributions of overconfidence. Across these three measures 88.2%, 70%, and 71.1% of the population exhibit overconfidence respectively. Only 9.2%, 16.5%, and 13.2% exhibit underconfidence. This establishes the antecedent for the hypotheses, widespread overconfidence, allowing for the rest of the analysis.

Table 1
Willingness-to-pay for capital and true value.

		Ability-Complement	Ability-Substitute
	WTP	4.947	5.878
Ex Ante Value		1.651	8.349
	Mean Overpay	3.296***	−2.470***
		(0.239)	(0.295)
Ex Post Value		1.546	8.342
	Mean Overpay	3.401***	−2.464***
		(0.264)	(0.297)

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$ “Ex Ante Value” refers to the value of capital assuming that Quiz B performance is the same as Quiz A performance. “Ex Post Value” refers to the actual value of capital on Quiz B performance. Standard errors are reported in parentheses. The p-values reflect two-sided paired t-tests.

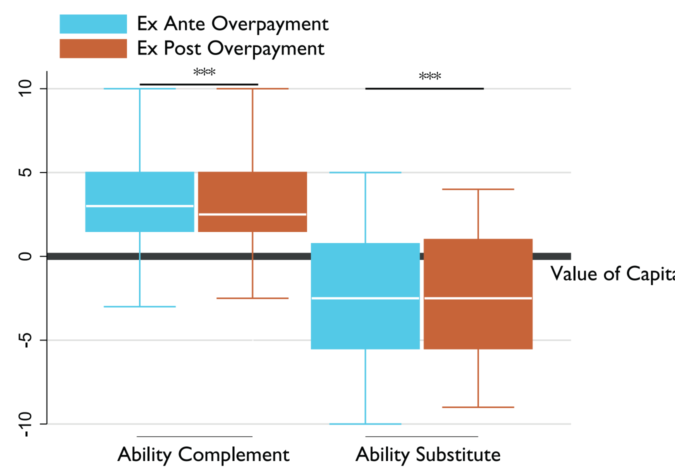


Fig. 4. Overpayment for Capital (in dollars).
Note: The white line located within the box indicates the median value. The box portion represents the interquartile range (25th percentile to 75th percentile) of the data. The whiskers represent the observations that fall within 1.5 times the interquartile range below (above) the 25th (75th) percentile. Overpayment is calculated as OP = WTP − risk-neutral optimal reservation price. The ex ante overpayment measure uses the risk-neutral optimal reservation price presuming performance is equal to Quiz A performance and the ex post overpayment measure uses the risk-neutral optimal reservation price given Quiz B performance. (***p<0.01).

4.2. Overpayment

Table 1 shows the WTP and true values of the capital. We find that subjects value the ability-complement, 4 extra questions, at $ 4.95 (SD = 2.79) on average. Hypothesis 1 states that subjects will have a reservation price that exceeds the value of the ability-complement. Throughout the paper we consider two benchmarks of optimal behavior. The ex ante benchmark considers what would be optimal for a risk-neutral subject given the ex ante performance on Quiz A. The ex post benchmark considers what would be optimal for a risk-neutral subject given the ex post outcome on Quiz B. Subjects overpay by $ 3.30 (SD = 2.95) using the ex ante benchmark of their performance on Quiz A (two-sided t-test, p<0.001). If their Quiz B performance had been identical to their Quiz A performance then paying $ 4.95−$ 3.30=$1.65 would have yielded $0 profit on average. Subjects overpay for the ability-complement by $ 3.40 (SD = 3.25) using the ex post benchmark (two-sided t-test, p<0.001). In other words, if subjects had paid $ 4.95−$ 3.40=$1.55 they would have profited $0 on average from the ability-complement. This overpayment can be seen visually in Fig. 4. These results are consistent with the model’s prediction that an overconfident agent overpays for an ability-complement (Proposition 1) and confirm Hypothesis 1.

Table 2
Valuation of capital as a function of beliefs.

	Ability-Complement			Ability-Substitute		
	(1)	(2)	(3)	(4)	(5)	(6)
Beliefs (IC for Quiz A)	0.452*** (0.131)			0.034 (0.171)		
Beliefs (Non-IC for Quiz A)		0.345*** (0.132)			−0.118 (0.171)	
Beliefs (Non-IC for Quiz B)			0.367*** (0.131)			−0.172 (0.170)
R^2	0.12	0.09	0.09	0.05	0.05	0.06
N	152	152	152	152	152	152

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$ Regressors include a constant and control dummies for question order. All models are OLS with robust standard errors.

Given that each correct question is worth $2.50, the WTP of $ 4.95 suggests that subjects expect to get an additional 1.98 of the 4 questions correct, implying a success rate of 0.495. This is a bit higher than the mean confidence of 0.452 elicited in the Confidence Stage (two-sided t-test, p=0.070). Risk-aversion predicts behavior would go in the opposite direction since subjects are paying a certain amount to receive an uncertain return.

In contrast, Hypothesis 2 states that agents will undervalue the ability-substitute on average. We find that on average the WTP for the ability-substitute is $ 5.88 (SD = 3.41). Given their weak performance, subjects on average undervalue the ability-substitute by $2.47 (SD = 3.64) using the ex ante benchmark (two-sided t-test, p<0.001), and $2.47 (SD = 3.66) using the ex post benchmark (two-sided t-test, p<0.001). Underpayment for the insurance can be seen visually in Fig. 4.

Given that a subject's belief of the fraction answered correctly is 0.452 on average, the implied risk-neutral WTP for the insurance would be $ 5.48. This difference of $ 5.88−$ 5.48=$0.40 is not significantly different from zero (two-sided t-test, p=0.295).

Hypotheses 3 and 4 state that higher beliefs in performance should cause higher payment for the ability-complement and lower payment for the ability-substitute. This can be viewed as a consistency check on individual behavior: subjects' purchase behavior should be consistent with their beliefs. We test these comparative statics by regressing WTP on beliefs. Table 2 displays the results. All regressions include indicators for question order and a constant term. In Columns (1)–(3) the outcome is the WTP for the ability-complement. We use our three measures of belief: the incentive compatible measure for Quiz A performance, the un-incentivized measure for Quiz A performance, and the un-incentivized measure for the not yet taken Quiz B. With all three measures we find that the coefficient is positive, showing that people who are more confident in their ability are more likely to buy the ability-complement. For Columns (1) and (2) the coefficients are highly significant, but not in Column (3). These results support Hypothesis 3. In Columns (4)–(6) we estimate the same regressions using the WTP for the ability-substitute as the outcome variable. In contrast the coefficients in these models are not significant. The standard errors are too large for the data to support Hypothesis 4. Taken together, the results suggest that subjects behave in a way that is consistent with their beliefs. Subjects do not, for instance, seem to be stating a random or otherwise arbitrary WTP that is unrelated to their true preferences and beliefs.

4.3. Excess entry

The central proposition of this paper is that the presence of an ability-complement can increase excess entry and make the agent worse off (Proposition 3). This is most clearly demonstrated by observing average earnings for each treatment within the Entry Stage.[9] Here we test Hypotheses 5 and 6, which state that access to the ability-complement will diminish average earnings while access to the ability-substitute will not. Table 3 displays the results. In the control, subjects earned an average of $15.18 (SD = 2.40), but with the ability-complement only $12.92 (SD = 3.67). The difference of $2.26 is significant (two-sided paired t-test, p<0.001) and represents a 14.9% decrease relative to the control earnings. Fig. 5 displays subject earnings in all three treatments. Panel (a) displays average earnings across the three treatments. Panel (b) displays earnings for those who selected the performance pay whom we label "entrants". The ability-complement increases performance amongst those who select in, but this small benefit is cancelled out by the fact that performance pay is much lower than random pay. Since the ability-complement dramatically increases entry, on average it makes subjects earn less. The results support Hypotheses 5 and 6.

Table 3
Entry and earnings.

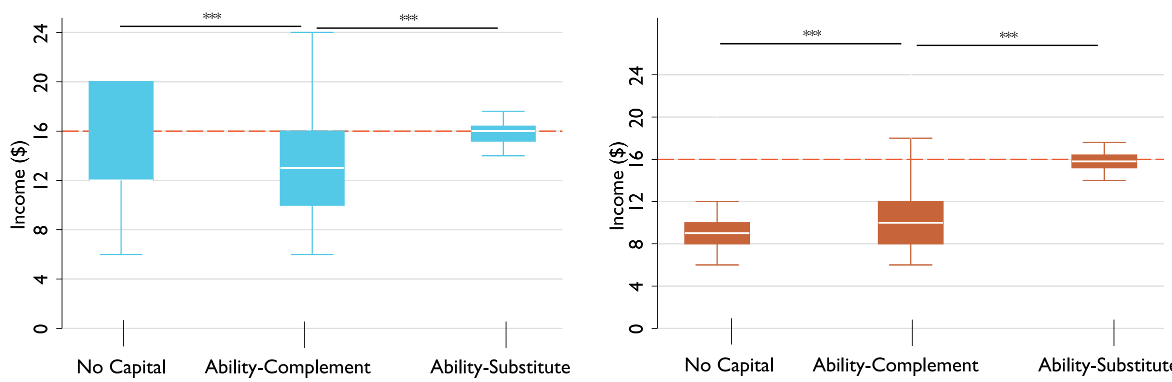
	No Capital	Ability-Complement		Ability-Substitute	
	Mean	Mean	Difference	Mean	Difference
Entry	0.138	0.572	0.434*** (0.043)	0.757	0.618*** (0.045)
Earnings	15.184	12.921	−2.263*** (0.311)	16.05	0.866*** (0.213)

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. "Difference" is the difference in means between the earnings in the capital (ability-complement or ability-substitute) condition and the earnings in the control condition. Standard errors are reported in parentheses. The p-values reflect two-sided paired t-tests.

We can unpack this effect by observing how the capital affected entry. We can measure this excess entry from both the ex ante and ex post perspective. The ex ante measurement of excess entry counts the number of subjects who choose performance pay and whose earnings extrapolated from Quiz A performance are below the expected random payment of $16.[10] As before the ex post measure of excess entry counts the number of subjects who choose performance pay and then earn less than the expected random payment of $16. Both measurements show that excess entry greatly increased. Using the ex ante measurement, excess entry went from 12.5% of the population in the control to 55.26% with the ability-complement, an increase of 42.76 percentage points

[9] Here we calculate average earnings by imputing $16 when a person chooses the random payoff. This barely changes the means and greatly reduces the noise. We do this to maintain consistency with the rest of the counterfactual analysis throughout the paper below.

[10] In the control and ability-substitute conditions we would compute earnings as if Quiz B had the same score as Quiz A. For the ability-complement condition, we assume that the quantity answered correctly equals the percentage answered correctly on Quiz A.



(a) Full Sample (b) Entrants Only

Fig. 5. Mean (Ex Post) earnings when subjects select entry.
Note: The white line located within the box indicates the median value. The box portion represents the interquartile range between 25th to 75th percentile of the data. The whiskers represent the observations that fall within 1.5 times the interquartile range below (above) the 25th (75th) percentile. (***p<0.01).

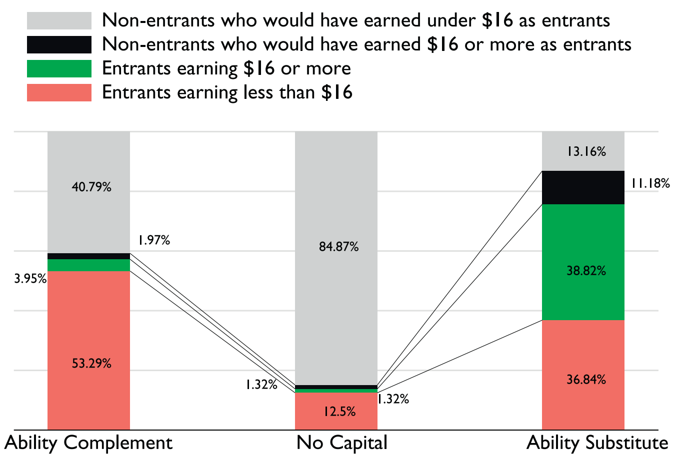


Fig. 6. Composition of choices and (Ex Post) outcomes when subjects select earning scheme.

(two-sided paired t-test, p<0.001). In contrast, profit-increasing entry increased from only 1.31% to 1.97% (two-sided paired t-test, p=0.320), less than a single percentage point. Using the ex post measurement, excess entry went from 12.5% of the population in the control to 53.29% with the ability-complement, which is an increase of 40.79 percentage points (two-sided paired t-test, p<0.001). In contrast, profit-increasing entry increased from only 1.32% to 3.95% (two-sided paired t-test, p=0.083), a mere 2.63 percentage points. The breakdown of actual choice and optimal choice is presented in Fig. 6.

This increase in excess entry is generated not by the acquisition of capital per se but by the acquisition of ability-complements. When the subjects acquire insurance, the ability-substitute, there is no such increase in excess entry. Earnings increased by $0.87 from $15.184 (SD = 2.40) to $16.05 (SD = 1.45), which is highly significant (two-sided paired t-test, p<0.001). Although excess entry did increase from 12.5% to 36.84% (two-sided paired t-test, p<0.001), this is offset by profit-increasing entry from 1.32% to 38.81% (two-sided paired t-test, p<0.001). The percentage of entrants who should have entered increases from 9.55% (= 1.32/(12.5 + 1.32)) in the control to 51.3% (= 38.82/(38.82 + 36.84)) in ability-substitute condition.

As with our analysis of overpayment, we now ask whether variation in over-entry can be explained by overconfidence. Hypotheses 7 and 8 state that the change in earnings from acquiring capital relative to no capital in the control condition, should be decreasing in overconfidence for the ability-complement, but increasing in overconfidence for the ability-substitute. Table 4 displays the results. All regressions include indicators for question order and a constant term. For Columns (1)–(2) the outcome variable is the earnings in the ability-complement condition minus the earnings in the control condition. Overconfidence is the incentive compatible belief about Quiz A performance minus actual performance on Quiz A for the results reported in Columns (1) and (3). The results reported in Columns (2) and (4) measure overconfidence using the non-incentivized measure of the belief about Quiz A performance. As predicted, coefficients in Columns (1) and (2) are negative, but the estimates are not statistically siginificant. This indicates that those with greater overconfidence may lose more money from the ability-complement. For Columns (3)–(4) the outcome is the earnings in the ability-substitute condition minus the earnings in the control condition. The results are consistent with Hypothesis 8. The coefficients are postive, as predicted, but statistically significant only when using the non-incentivized measure of belief. Fig. 7 displays the relationships using the incentivized measure of overconfidence. In summary, the results are consistent with Hypotheses 7 and 8, but the results do not reach conventional levels of statistical significance, quite likely because the measure of overconfidence contains a considerable degree of noise.

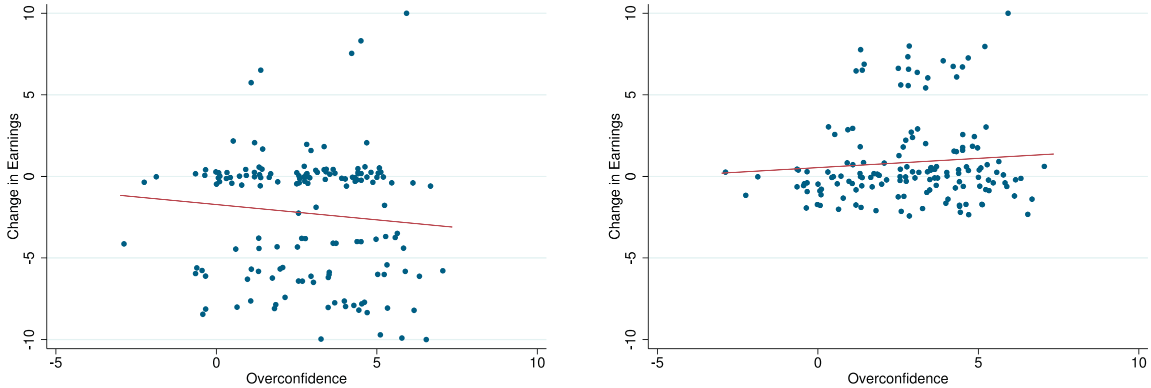
Table 4
Change in earnings from acquiring capital.

	Ability-Complement		Ability-Substitute	
	(1)	(2)	(3)	(4)
Overconfidence (Ex-Ante)	−0.221		0.099	
	(0.167)		(0.091)	
Overconfidence (Non-IC Quiz A)		−0.181		0.208*
		(0.175)		(0.120)
R^2	0.02	0.02	0.02	0.04
N	152	152	152	152

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$ Change in earnings is earnings from Quiz B with capital minus earnings in Quiz B without capital. We impute 16 dollars for the random payment. Overconfidence is the incentive compatible measurement of confidence on Quiz A minus performance on Quiz A. Regressors include a constant and control dummies for question order. All models are OLS with robust standard errors.

4.4. Robustness

The theoretical predictions of the model are consistent with the experimental results. In order to better provide evidence sup-



(a) ability-complement (b) ability-substitute

Fig. 7. Change in earnings from capital as a function of overconfidence.

porting overconfidence as the underlying mechanism, we conduct a counterfactual analysis. Would the excess entry results disappear if people were not overconfident? We proceed by calculating expected earnings under the assumption that subjects' beliefs are true. In other words, we now test for excess entry under the assumption that the incentive-compatible confidence responses are a perfectly accurate reflection of future performance. If beliefs were true, then in the control condition the average earnings would have been \$16.18 (SD = 3.90), the ability-complement would have increased earnings to \$17.74 (SD = 4.75) (two-sided paired t-test, p=0.001) and the ability-substitute would have increased earnings to \$18.37 (SD = 3.20) (two-sided paired t-test, p<0.001). In summary, without overconfidence both types of capital would have increased earnings.

Looking closer at individual decisions, a person should never enter if they believe the distribution of their performance earnings is first-order stochastically dominated by the distribution of random earnings. We take subjects' elicited beliefs for each question on Quiz A to construct the distribution of their beliefs for their score. Using the ex ante logic that Quiz B is likely to be the same as Quiz A, we find that 13 subjects believe that the random earnings first-order stochastically dominate their performance earnings. Of these 13 subjects 0 choose performance earnings. It seems that subjects are behaving quite reasonably given their beliefs. We conduct the same analysis under the ability-complement condition. For this condition 9 subjects believe the random earnings first-order stochastically dominate their performance earnings. Of these 9 subjects 4 choose performance earnings. This is a violation of monotonicity but represents less than 3% of the subject pool. As a whole these findings suggest that much of behavior is consistent with the elicited beliefs, and the evidence is consistent with the claim that overconfidence is driving suboptimal behavior.

In Appendix C, we disaggregate the sample by order and conduct a split-sample analysis on each order individually. We replicate Tables 1–4, and show that the results are not driven by any one particular order.

4.5. The role of risk aversion

The preceding analysis assumes that subjects are risk-neutral and therefore maximize monetary earnings. It is possible, however, that risk preferences influence subjects' choices. Risk aversion should affect a subject's WTP for the capital. The ability-complement is expected to increase the variance of earnings. If z is the random variable that represents how many questions a person gets correct on a 10-question quiz then $1.4z$ represents how many questions a person gets correct on a 14-question quiz. The bonus questions nearly double the variance of correct answers. The ability-substitute, on the other hand, should reduce the variance of earnings. The formula for earnings without the capital is \$ $2.5z$ and with the substitute is \$ $10 + 1.5z$. Thus the variance of earnings with the substitute is approximately 36% of the variance without the substitute. Therefore risk aversion should reduce the valuation of the complement and increase the valuation of the substitute. This goes against our theoretical predictions (Hypotheses 1 and 2) and our findings. This implies that our overpayment and underpayment results actually understate the degree of distortion in subjects' valuations.

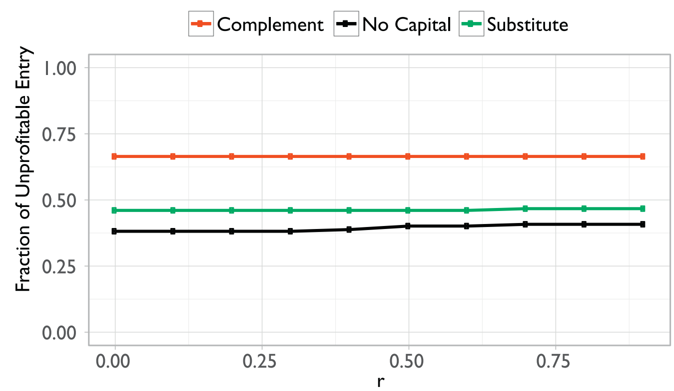


Fig. 8. Simulated Overentry with Risk Aversion.

Risk aversion may also distort subjects' decision to enter. To examine this possibility, we simulate the incidence at which subjects would choose unprofitable entry under varying levels of risk aversion. We assume that entry depends on the ex ante distribution of subjective beliefs about performance, while actual expected profit from entry depends on the distribution of performance implied by each subject's actual performance on Quiz A. The simulated entry decision compares the expected utility of entry versus the lottery option using using a power utility function $u(x) = \frac{x^{1-r}}{1-r}$ with constant-relative-risk-aversion coefficient r. Risk-aversion is increasing in the value of r while $r = 0$ implies risk neutrality. Fig. 8 illustrates the results of the simulation.

Simulated risk-neutral rates of overentry are 38, 66 and 46 percent for the control, complement and substitute treatments. These rates are substantially higher than those observed in the experiment, indicating that subjects actually enter less than one would infer based on their beliefs. Importantly, the simulation also shows that entry decisions are not particularly sensitive to risk aversion. Increasing r from 0 to 1 results only in a small increase in the predicted overentry rate of the control condition, from 38 to 40 percent. Because the predicted entry behavior is independent of the degree of risk aversion, risk aversion should have no effect on our result that free ability-complements leads to lower payoffs.

5. Conclusion

In this paper we make the conceptual distinction between capital that is complementary with ability and capital that is a substitute with ability. We theoretically show that an overconfident agent will overvalue an ability-complement. Moreover, because an ability-complement increases overconfidence in productivity, the overconfident agent will select capital that exacerbates his distorted expectations about future output. This will lead to increased excess entry. Ironically, the agent undervalues the ability-substitute which would mitigate his overconfidence. The implication is that ability-complements can make an overconfident agent worse off.

As a proof of concept, we run a controlled laboratory experiment in which we find behavior consistent with the predictions. Subjects state WTP for ability-complements that are too high and WTP for ability-substitutes that are too low. The results demonstrate that providing an ability-complement can increase excess entry and decreases earnings.

Entrepreneurship is another domain in which these principles may manifest. Numerous studies document pervasive overconfidence among entrepreneurs (Åstebro, Herz, Nanda, and Weber, 2014). The model presented in this paper shows that overconfidence could lead entrepreneurs to over-invest in ability-complements and underinvest in ability-substitutes. The specifics of how this may manifest are as varied as the entrepreneurial endeavors themselves. For example, a new small business may have to decide about the scale and location for its initial property. Bigger and more trafficked properties would be ability-complements if they generate more revenue for more successful businesses, yet such properties are far more costly. Access to large and highly-trafficked properties may cause small businesses to fail faster and with greater losses. In contrast, the opportunity to re-sell the property for a profit (either due to rising neighborhood property values or due to inexpensive structural improvements) is an ability-substitute — it is a feature that is valuable only if the business fails, and this feature may be overlooked by the business.[11]

Balancing liberty with consumer error may be a challenge for policy makers. In some contexts it may be welfare-improving to tax ability-complements and subsidize ability-substitutes. Libertarian paternalistic policies Thaler and Sunstein (2008) have the advantage of not restricting choice, but may be ineffective in overcoming people's robust overconfidence. Recent evidence suggests that providing information about overconfidence has no effect on behavior Tasoff and Letzler (2014). If the additional excess entry stemming from ability-complements is especially severe, limiting choice may be a preferred option. The U.S. Securities and Exchange Commission restricts investment in hedge funds to accredited investors who meet minimum income and asset requirements. Likewise requiring mandatory low-cost ability-substitutes may impose low losses on those with accurate beliefs while generating large benefits to overconfident people.[12] On the other hand restricting choice is strongly paternalistic and can also lead to welfare loss if improperly calibrated. Requiring ability-substitutes to be packaged with ability-complements may be an appropriate compromise. For example, permitting uneducated and inexperienced investors to engage in risky speculation after they obtain sufficient basic financial literacy (ability-substitute) by passing a test might be an optimal policy middle-ground.

[11] Of course there are other motivations for choosing a large property or a prime location (e.g. create a buzz, advertisement). The point here is to provide a concrete example for what ability-complements and ability-substitutes *might* be for an entrepreneur.

[12] We credit Robert Letzler for this point.

Appendix A. Proofs

Proof of Proposition 1. Differentiate (3) with respect to $\hat{\theta}$. By the Envelope Theorem

$$\frac{\partial \bar{p}}{\partial \hat{\theta}} = e(1,\hat{\theta})\frac{\partial y(1,\hat{\theta})}{\partial \hat{\theta}} - e(0,\hat{\theta})\frac{\partial y(0,\hat{\theta})}{\partial \hat{\theta}} \tag{5}$$

Because this is an ability-complement $\partial y(1,\hat{\theta}) > \partial y(0,\hat{\theta})$. Hence $\frac{\partial \bar{p}}{\partial \hat{\theta}} > 0$ if $e(1,\hat{\theta}) > e(0,\hat{\theta})$. This follows from the implicit definition of $e(k,\hat{\theta})$ given by $f'(1-e(k,\hat{\theta})) = y(k,\hat{\theta})$ and by assumptions $y(1,\hat{\theta}) > y(0,\hat{\theta})$ and $f''(\cdot) < 0$.

To show that entry is increasing in $\hat{\theta}$ we use the implicit function theorem:

$$\frac{\partial e(k,\hat{\theta})}{\partial \hat{\theta}} = -\frac{\partial^2 u(k,e,\hat{\theta})/\partial e \partial \hat{\theta}}{\partial^2 u(k,e,\hat{\theta})/\partial e^2} = -\frac{\partial y(k,\hat{\theta})/\partial \hat{\theta}}{f''(1-e(k,\hat{\theta}))} > 0. \tag{6}$$

The inequality holds because the numerator is positive by assumption and the denominator is negative by assumption. □

Proof of Lemma 1. The derivative of the reservation price with respect to $\hat{\theta}$, keeping e fixed is $e(\frac{\partial y(1,\hat{\theta})}{\partial \hat{\theta}} - \frac{\partial y(0,\hat{\theta})}{\partial \hat{\theta}})$. From the definition of ability-substitutes the parenthetical term is negative. □

Proof of Proposition 2. From Equation (5) we must have $\frac{\partial y(0,\hat{\theta})/\partial \hat{\theta}}{\partial y(1,\hat{\theta})/\partial \hat{\theta}} > \frac{e(1,\hat{\theta})}{e(0,\hat{\theta})}$. The first-order condition for entry yields $y(k,\hat{\theta}) = f'(1-e(k,\hat{\theta}))$. Since f' is a strictly decreasing function we can take the inverse to solve: $e(k,\hat{\theta}) = 1 - f'^{-1}(y(k,\hat{\theta}))$. This is substituted into the inequality to get the desired expression. □

Proof of Lemma 2. Total utility can be expressed as

$$u(k,e,\theta) = \underbrace{\int_0^{e(k,\theta)} y(k,\theta) - f'(1-e)de}_{\text{surplus}} + \underbrace{\int_{e(k,\theta)}^{e(k,\hat{\theta})} y(k,\theta) - f'(1-e)de}_{\text{dead-weight loss of overconfidence}} \tag{7}$$

Because $e(1,\theta) > e(0,\theta)$ (see Proposition 1) and $y(1,\theta) > y(0,\theta)$ the surplus term is larger when $k=1$ then when $k=0$. Observe that the integrand in the DWL term is always weakly negative because $y(k,\theta) = f'(1-e(k,\theta))$ and f' is increasing in e. It is sufficient to show that the DWL term is lower in magnitude for $k=0$ then $k=1$. The DWL term can be rewritten

$$DWL_k = \int_{y(k,\theta)}^{y(k,\hat{\theta})} e(k,\hat{\theta}) - 1 + f'^{-1}(y)dy.$$

A decrease in DWL from $k=0$ to $k=1$ is equivalent to

$$\int_{y(0,\theta)}^{y(0,\hat{\theta})} e(0,\hat{\theta}) - \left(1 - f'^{-1}(y)\right)dy > \int_{y(1,\theta)}^{y(1,\hat{\theta})} e(1,\hat{\theta}) - \left(1 - f'^{-1}(y)\right)dy \tag{8}$$

Observe that $y(0,\hat{\theta}) - y(0,\theta) \geq y(1,\hat{\theta}) - y(1,\theta)$ from the definition of ability-substitutes. Also observe from the inverse function theorem $f'^{-1\prime}(y) = [f''(f'^{-1}(y))]^{-1} < 0$, since $f' < 0$, so

$$f'^{-1\prime\prime}(y) = \frac{d}{dy}[f''(f'^{-1}(y))]^{-1} = \frac{-f'^{-1\prime}(y)f'''(f'^{-1}(y))}{[f''(f'^{-1}(y))]^2} > 0$$

because $f'' > 0$.

This implies that the second term in the integrand of both sides of (8) is concave. Observe that at the upper limit of integration the

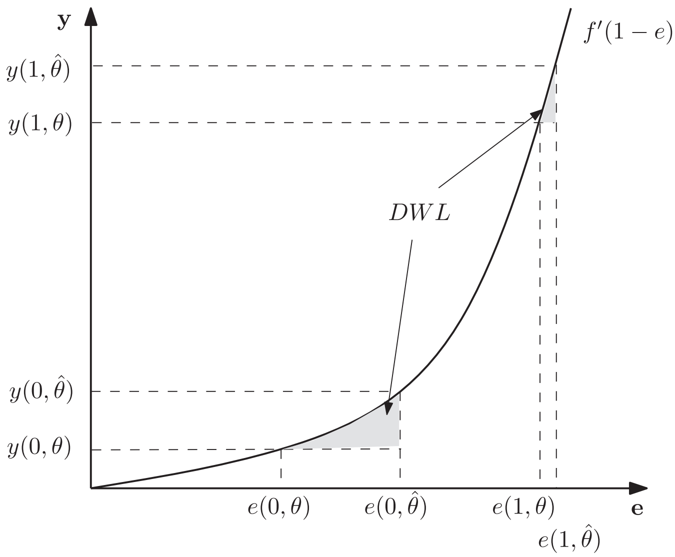


Fig. 9. DWL of over-entry.

integrand for both sides of the inequality is zero. As we go from the upper limit of integration downward, the integrand on the LHS is point-by-point larger than the integrand on the RHS because the concavity of the second term implies that it decreases more on the LHS due to $y(0,\hat{\theta}) < y(1,\hat{\theta})$. This is illustrated for clarity in Fig. 9. Because the distance of the support on the LHS is equal to or larger than the distance of the support on the RHS, due to the definition of ability-substitutes, inequality (8) holds. □

Proof of Proposition 3. If the agent purchases the capital before and after, a small increase in the price will unambiguously decrease welfare. If the current price is above the reservation price a small increase in the price will have no effect on welfare. If the current price equals the reservation price, a small increase will cause the agent to switch from purchasing the capital to not purchasing the capital. Here we show the necessary and sufficient conditions for this increase in price to decrease utility. The utility at the reservation price is

$$\bar{u} = e(0,\hat{\theta})y(0,\hat{\theta}) + f(1-e(0,\hat{\theta})) - e(1,\hat{\theta})[y(1,\hat{\theta}) - y(1,\theta)] \tag{9}$$

$$\Delta u = e(0,\hat{\theta})[y(0,\theta) - y(0,\hat{\theta})] + e(1,\hat{\theta})[y(1,\hat{\theta}) - y(1,\theta)] < 0 \tag{10}$$

$$\frac{y(1,\hat{\theta}) - y(1,\theta)}{y(0,\hat{\theta}) - y(0,\theta)} < \frac{e(0,\hat{\theta})}{e(1,\hat{\theta})} \tag{11}$$

The fact that $e(k,\hat{\theta}) = 1 - f'^{-1}(y(k,\hat{\theta}))$ gives the stated inequality. For an ability-complement the LHS is greater than 1, and the RHS is less than 1, and thus the inequality cannot be satisfied. □

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.socec.2016.12.005.

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