Security Design in a Production Economy with Flexible Information Acquisition

Ming Yang & Yao Zeng

Duke & Harvard

June 2013

Motivation

Production Economy

- Entrepreneur: undertakes risky project if he gets financing
- Investor: capable of acquiring costly info about project and thus helps screen project through financing decision (Bond-Edmans-Goldstein 12, Da Rin-Hellmann-Puri 11, etc.)

Friction

- Dependence and separation of real production and info production

Question

- What is the optimal financing given such friction?

Contribution

Entrepreneur's trade-off

- Increase own share vs. induce favorable info acquisition

Results

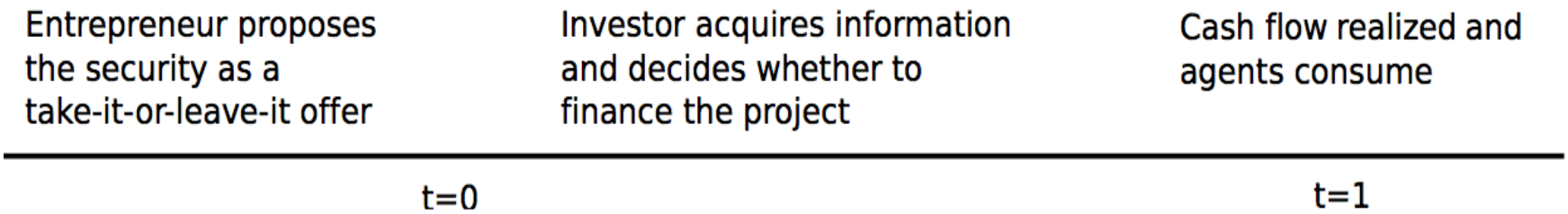
- Standard debt
- Convertible preferred stock (Kaplan-Stromberg 03)
- Friction $\uparrow \Longrightarrow$ debt $\rightarrow$ convertible preferred stock

Model Highlights

- A unified framework for distinct securities
- Over continuous states, without distributional assumptions
- Flexible info acquisition / rational inattention

Financing Entrepreneurial Production

- Two dates: $t = 0, 1$.
- Two risk neutral agents $u = c_0 + c_1$
  - Entrepreneur: zero initial wealth
  - Investor: deep pocket
- Technology
  - Investment k at $t = 0$ generates uncertain cash flow θ at $t = 1$ (common prior Π)
  - Entrepreneur's human capital inalienable (relaxed later)
  - Entrepreneur needs to raise k by selling $s(\theta) \in [0, \theta]$ to investor
- Timeline



Investor's Flexible Information Acquisition

- Facing offer $s(\theta) - k$, investor chooses
  - Info structure $f(x|\theta)$
  - Decision rule $\sigma : x \to [0, 1]$
- Innovation
  - Conventional: parametric restrictions on $f(x|\theta)$
  - Flexible: any info structure feasible, incurs a cost proportional to the amount of info (rational inattention, Sims 03, etc.)
- A 2-state example: let $m(\theta) = f(x = 1|\theta)$, then

	$x = 1$	$x = 0$
$\theta = 1$	$m(1)$	$1 - m(1)$
$\theta = 0$	$m(0)$	$1 - m(0)$

and $|m(1) - m(0)|$ reflects the informativeness

Investor's Flexible Information Acquisition

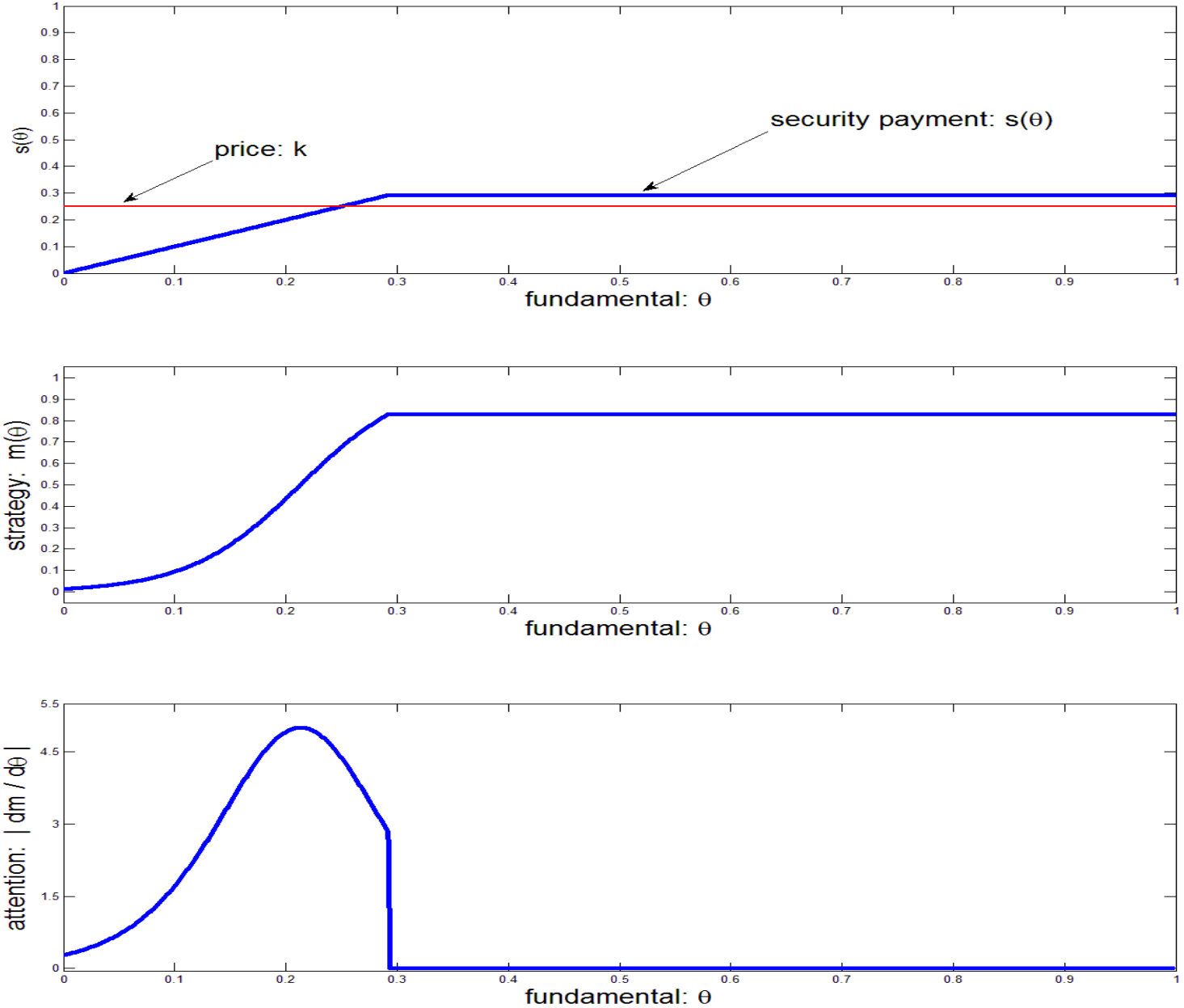
- Rational inattention with binary choice (Woodford 08, Yang 12)
  - Actions $\{reject = 0, accept = 1\}$ and signals $x \in \{0, 1\}$
  - Binary info. structure $m : \mathbb{R}_+ \to [0, 1]$
    - $m(\theta) =$ prob. of observing signal 1 if true state is θ
    - choice variable of investor
    - incurs cost $c(m) = \mu \cdot I(m)$
    - $|dm/d\theta|$ reflects allocation of attention
- Amount of info $I(m)$ (Shannon 48)
  - Reduction of uncertainty through observing x generated by m

$$\begin{aligned} I(m) &= H(prior) - H(posterior) \\ &= \mathbf{E}g(m(\theta)) - g(\mathbf{E}m(\theta)) \ , \end{aligned}$$

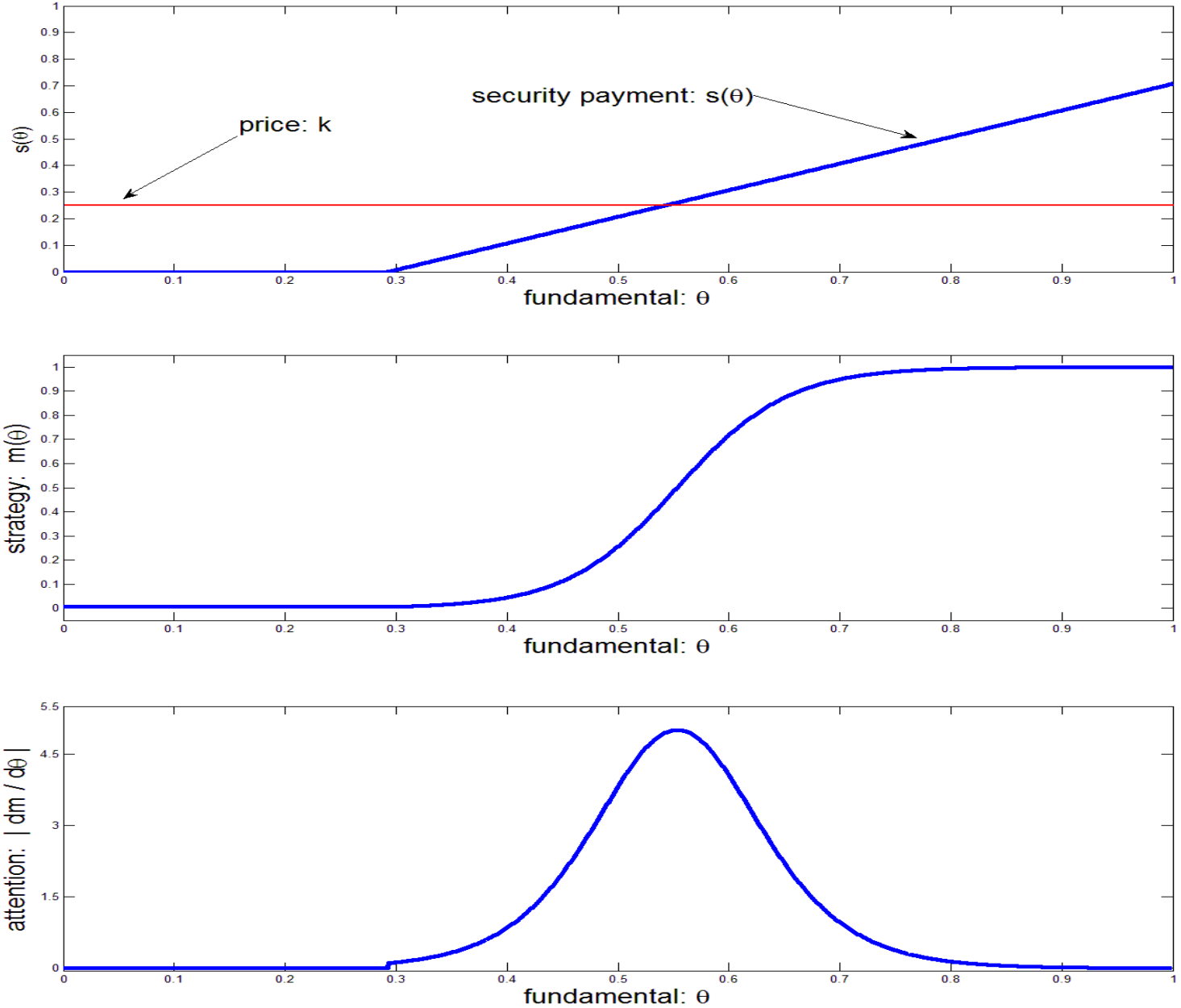
where $H(\cdot)$ is Shannon's entropy and

$$g(m) = m \ln m + (1 - m) \ln (1 - m)$$

Flexible information Acquisition–Example 1: Debt



Flexible information Acquisition–Example 2: Equity



Solving Binary Decision Problem with Flexible Information Acquisition

Decision problem:

$$\max_{m \in \Omega} V^* (m) \triangleq \mathbf{E} \left[m(\theta) \cdot (s(\theta) - k) \right] - \mu \cdot I(m),$$

where

$$\Omega \triangleq \left\{ m \text{ measurable} : m(\theta) \in [0,1] \text{ for all } \theta \in \Theta \right\}.$$

Proposition 1: Let $m \in \Omega$ be an optimal strategy and

$$\overline{p} = \mathbf{E} m(\theta)$$

be the corresponding unconditional probability of taking action 1. Then,
i) the optimal strategy is unique;

Solving Binary Decision Problem (cont'd)

ii) there are three possibilities for the optimal strategy $m(\cdot)$:

a) if

$$\mathbf{E}\exp\left(-\frac{s(\theta)-k}{\mu}\right) \leq 1 \ ,$$

then accept for sure without info acquisition, i.e., $m(\theta) = 1$ *a.s.;*

b) if

$$\mathbf{E}\exp\left(\frac{s(\theta)-k}{\mu}\right) \leq 1 \ ,$$

then reject for sure without info acquisition, i.e., $m(\theta) = 0$ *a.s.;*

c) otherwise, $m(\theta) \in (0,1)$ *a.s. and is characterized by*

$$\frac{s(\theta)-k}{\mu} = \ln\left(\frac{m(\theta)}{1-m(\theta)}\right) - \ln\left(\frac{\overline{p}}{1-\overline{p}}\right) \ .$$

Entrepreneur's Security Design Problem

- Entrepreneur chooses $s : \mathbb{R}_+ \to \mathbb{R}_+$ to maximize

$$\mathbf{E}\left[m_s(\theta) \cdot (\theta - s(\theta))\right]$$

subject to

  - $s(\theta) \in [0, \theta]$
  - investor's best response $m_s(\cdot)$ given by *Proposition 1*

Optimal Security without Inducing Information Acquisition

- *Proposition 2: If the optimal security $s^*(\theta)$ induces the investor to accept the offer without acquiring information, then it takes the form of standard debt:*

$$s^*(\theta) = \min(\theta, D^*)$$

- Intuition: as flat as possible to deter info acquisition (*"ignorance is bliss"*–Holmstrom 12)
- Consistent with the conventional wisdom of info insensitiveness
  - Myers-Majluf 84; Gorton-Pennacchi 90; DeMarzo-Duffie 99

Optimal Security Inducing Information Acquisition

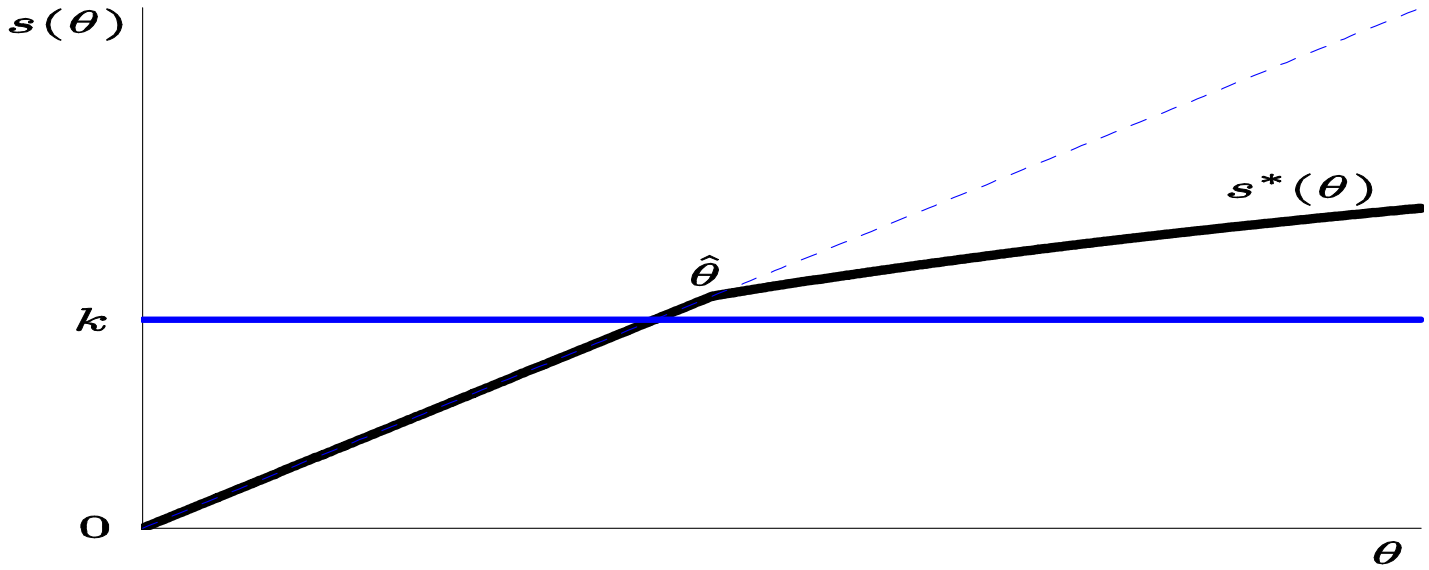
- *Proposition 3: If the optimal security $s^*(\theta)$ induces the investor to acquire information, then it takes the following form:*

$$s^*(\theta) = \begin{cases} \theta & \text{if } 0 \leq \theta < \widehat{\theta} \\ \widehat{s}(\theta) & \text{if } \theta \geq \widehat{\theta} \end{cases},$$

where $\widehat{\theta} > 0$, $d\widehat{s}(\theta) / d\theta \in (0, 1)$, ($\widehat{s}(\theta)$ is given in paper).

Optimal Security Inducing Information Acquisition (cont'd)

- (Participating) convertible preferred stock



- Intuition: ignorance is no longer bliss
  - Friction $\Longrightarrow$ deviate from first-best (45° line)
  - Screening/info acquisition makes sense only if $m(\theta) \uparrow$
  - Entrepreneur's payoff is $\mathbf{E}\left[m(\theta) \cdot (\theta - s(\theta))\right]$
  - Better to deviate at high states
- Empirical evidence: 80% VC contracts are convertible preferred stock and half of them are participating

New Pecking Order

Proposition 4: When the project is financed (with positive prob.):

1. *if* $E[\theta] \leq k$, $s^*(\theta)$ *is convertible preferred stock; or*
2. *if* $E[\theta] > k$, $s^*(\theta)$ *is either convertible preferred stock or standard debt.*

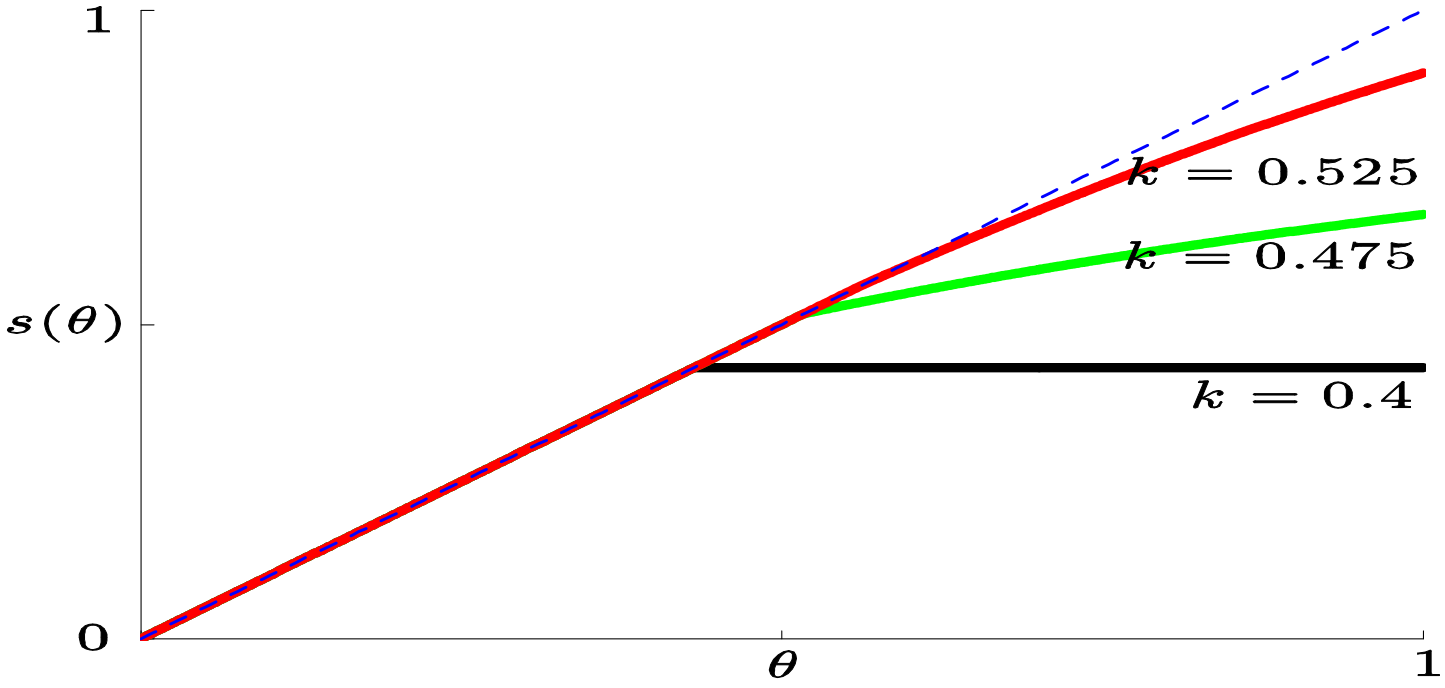
Intuition

- Negative NPV $\Longrightarrow$ no investment unless info updating
  - Use convertible preferred stock to *screen in* good projects
- Positive NPV
  - Modest prior $\Longrightarrow$ invest as status quo, but info still valuable
    - Use convertible preferred stock to *screen out* bad projects
  - Good prior $\Longrightarrow$ always invest, not worth to acquire info
    - Use debt to deter info acquisition, *ignorance is bliss*

A *unified framework* for debt and convertible preferred stock

New Pecking Order–Comparative Statics

- Change of required investment k (with $\mathbf{E}[\theta] = 0.5$)



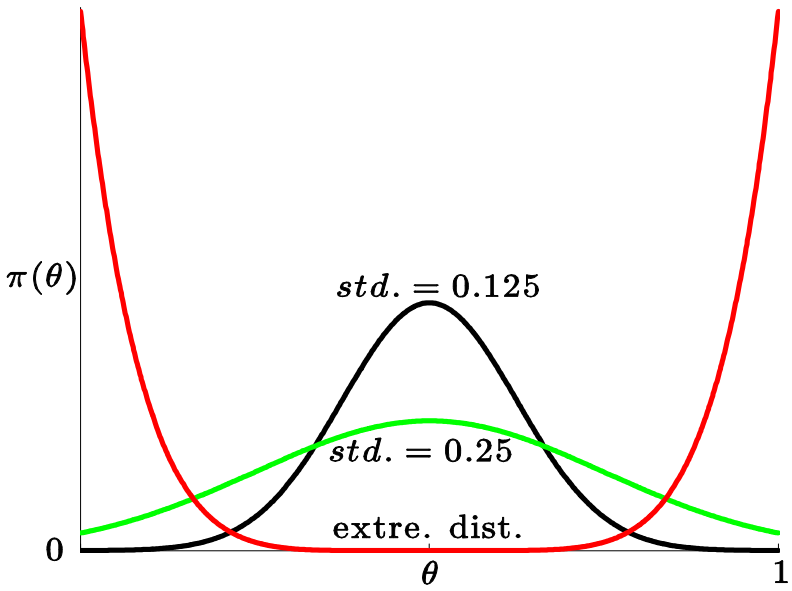
- $k = 0.525$ (screen in); $k = 0.475$ (screen out); $k = 0.4$ (ignorance is bliss);
- Intuition: $k \uparrow \Longrightarrow$ info acquisition more relevant $\Longrightarrow$ friction $\uparrow \Longrightarrow$ convertible preferred stock

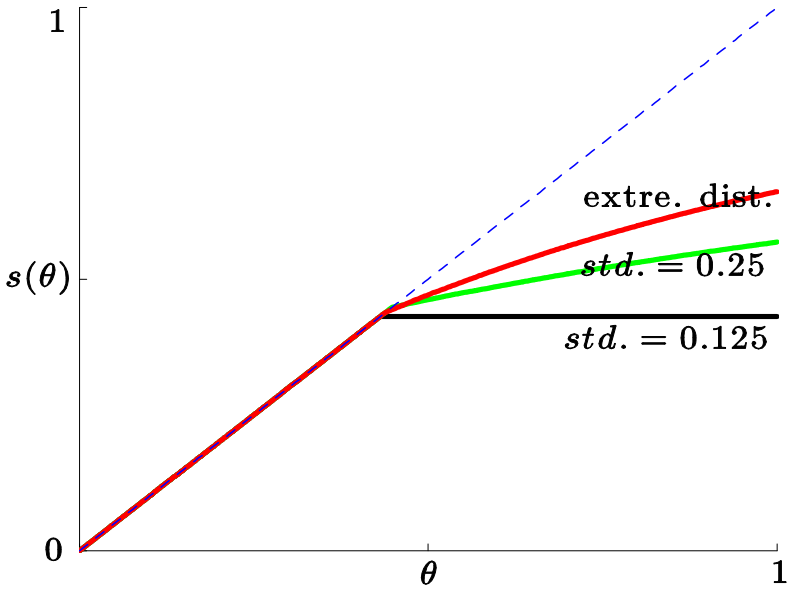
Welfare Analysis

- Efficiency benchmark: real production & info production centralized
- *Proposition 5: When the project is financed (with positive prob.):*
  1. *Standard debt is optimal iff the friction is not severe in the sense that the optimal security achieves social efficiency;*
  2. *Convertible preferred stock is optimal iff the friction is severe in the sense that even the optimal security cannot achieve social efficiency.*
- Remark
  - Friction (in)significant $\Longrightarrow$ real production (doesn't) depend on info production $\Longrightarrow$ info acquisition (un)desired $\Longrightarrow$ calls for (debt) convertible preferred stock
- Implication
  - Debt / convertible preferred stock popular in industries with less / more friction

Welfare Analysis–Comparative Statics

- Change of prior





- Intuition: uncertainty $\uparrow \Longrightarrow$ info acquisition more relevant $\Longrightarrow$ friction $\uparrow \Longrightarrow$ convertible preferred stock
- More comparative static analysis in paper...

Exchange Economy vs. Production Economy

Exchange economy

- Aggregate cash flow independent of financial decision
- Info acquisition $\left.\begin{matrix}\textit{is costly}\\ \textit{causes adverse selection}\end{matrix}\right\} \Longrightarrow$ always reduce social surplus
- Ignorance is always bliss, debt is always optimal (Yang 12)

Production economy

- Aggregate cash flow depends on financial decision
- Info acquisition $\left.\begin{matrix}\textit{is still costly}\\ \textit{but helps screen projects}\end{matrix}\right\} \Longrightarrow$ may or may not reduce social surplus
- Depending on which force dominates
- Debt or convertible preferred stock could be optimal

Conclusion

Summary

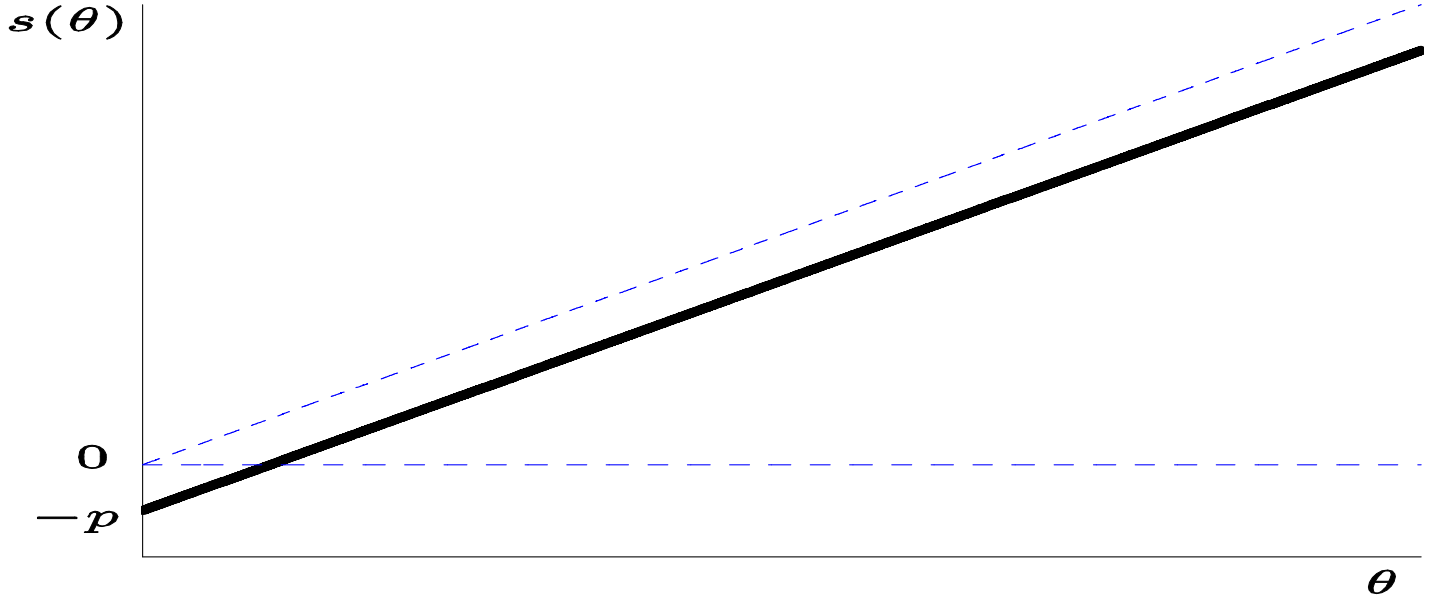
- Friction: dependence and separation of real and info production
- Different projects financed by different security design
- Production economy vs. exchange economy

Contributions

- Flexible info acquisition: security design over continuous states without distributional assumptions
- A unified framework for distinct securities

Transfer is not Optimal

- *Proposition 6: To transfer the project at any fixed price is not optimal for the entrepreneur.*
- Argument:



- Intuition
  - Screening/info acquisition makes sense only if $m(\theta) \uparrow$
  - Not good to deviate uniformly over all states, better to deviate at high states

Multiple > 1

Proposition 7: The multiple of the optimal convertible preferred stock is greater than one, i.e., $\widehat{\theta} > k$.

- Natural result, consistent with empirical evidence

Amount of information and information Cost

- Mutual info $I(m)$ (Shannon 48)
  - Reduction of uncertainty through observing x generated by m

$$\begin{aligned} I(m) &= H(prior) - H(posterior) \\ &= \mathbf{E}g(m(\theta)) - g(\mathbf{E}m(\theta)) \ , \end{aligned}$$

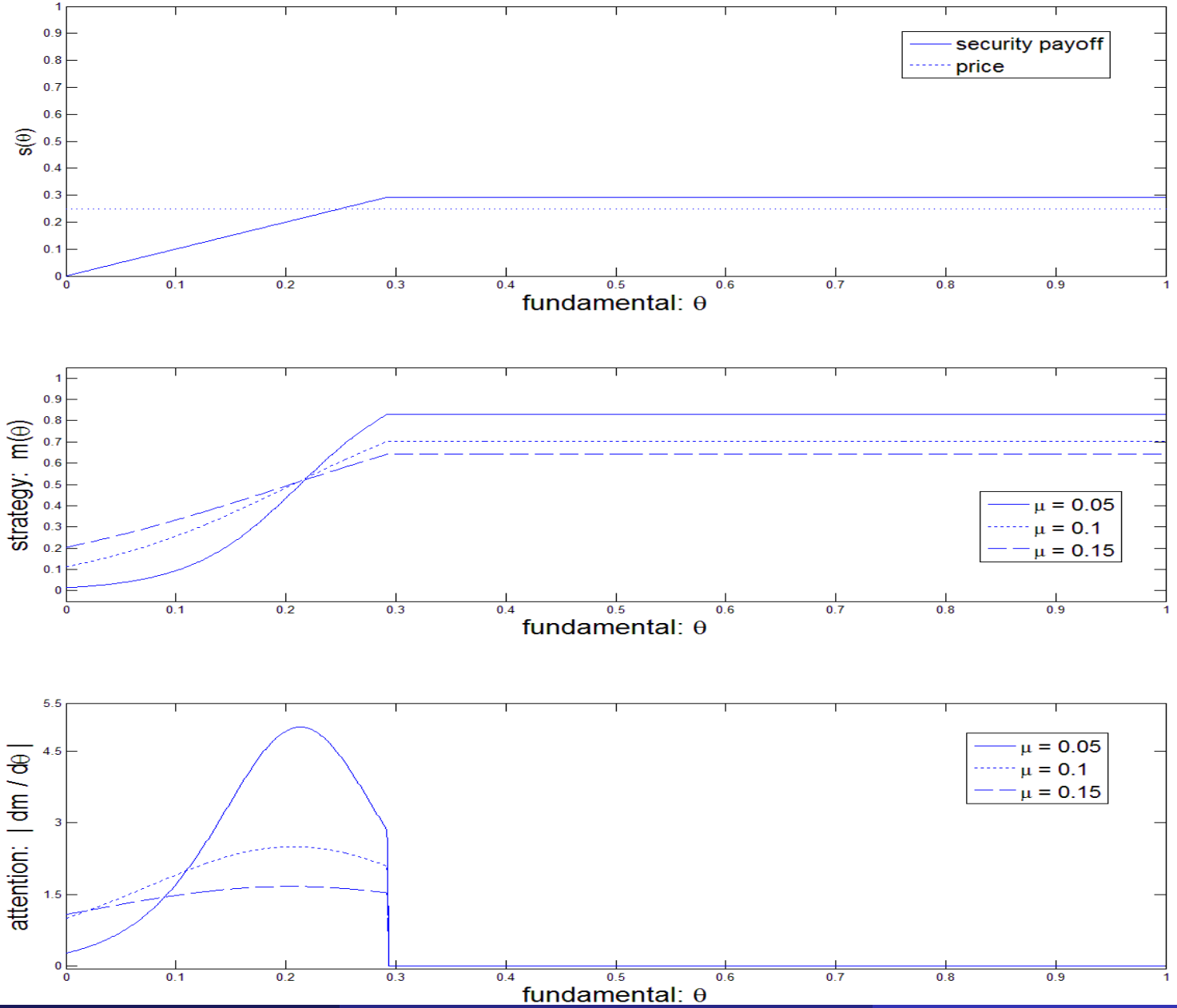
  where $H(\cdot)$ is Shannon's entropy and

$$g(m) = m \ln m + (1-m) \ln (1-m)$$

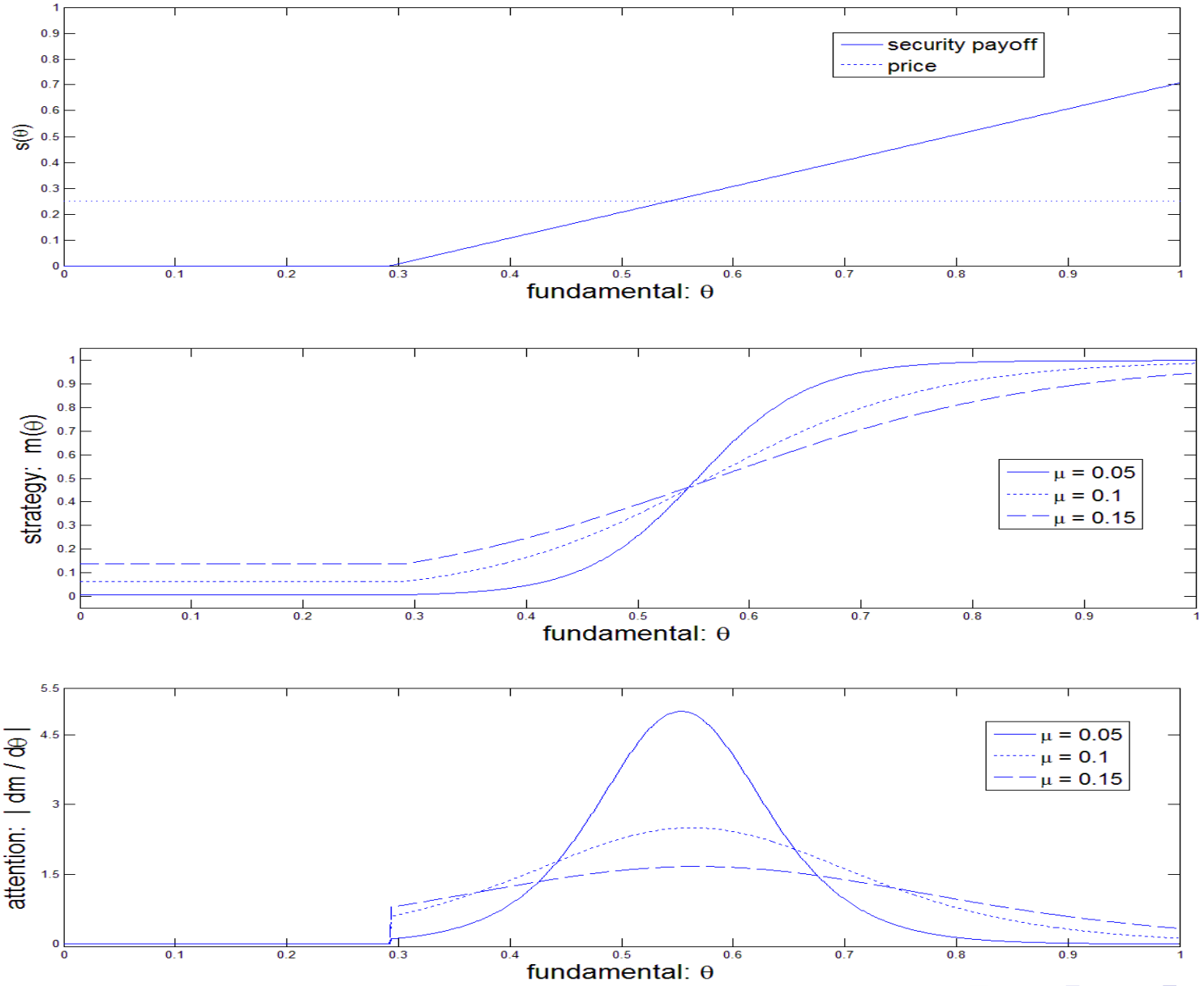
- Info cost:

$$c(m) = \mu \cdot I(m)$$

Flexible information Acquisition–Example 1: Debt



Flexible information Acquisition–Example 2: Equity



Information Adjusted NPV Criterion

- *Proposition A1: The project is financed with positive prob. iff*

$$\mathbf{E}\left[\exp\left(\frac{\theta - k}{\mu}\right)\right] > 1 \ .$$

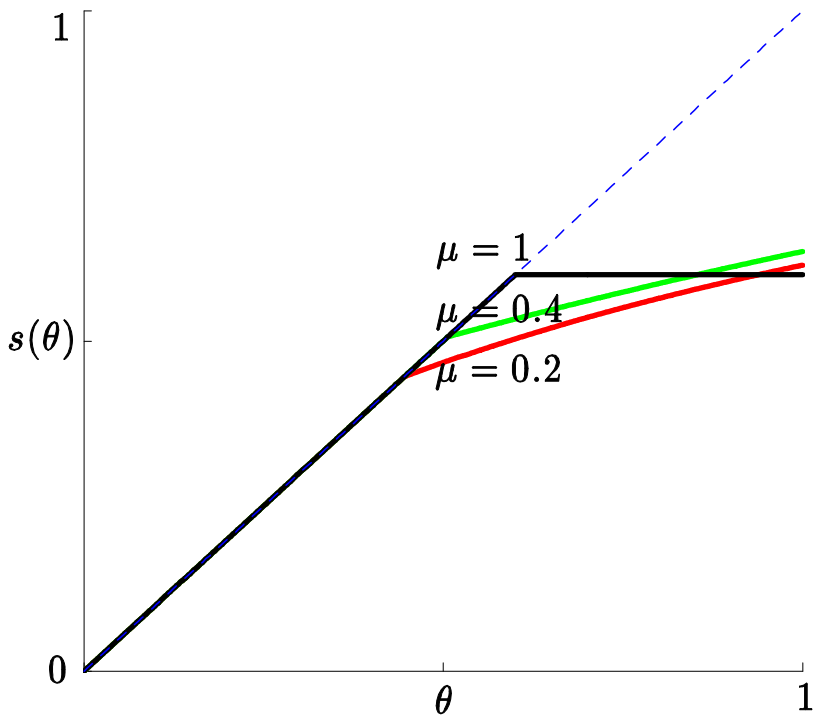
- A new investment criterion: different from NPV
- Nests NPV criterion by taking $\mu \to \infty$

Equilibrium Definition

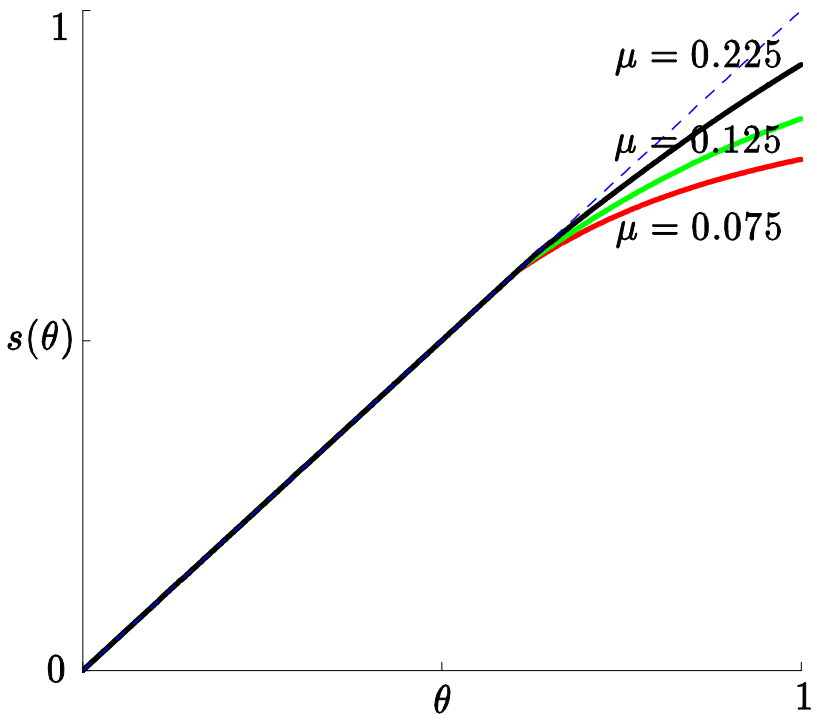
Definition: *The sequential equilibrium is defined as a collection of the entrepreneur's optimal security* $s^*(\theta)$ *and the investor's optimal decision rule of information acquisition* $m_s^*(\theta)$ *based on which:*

1. *Given* Π, k *and* μ, $s^*(\theta)$ *and* $m_s^*(\theta)$ *maximize the expected payoffs of the entrepreneur and the investor, respectively;*
2. *Both agents use the Bayes' rule to update their beliefs about the fundamental* θ, *and follow sequential rationality.*

Change of Information Cost: Positive vs. Negative NPV

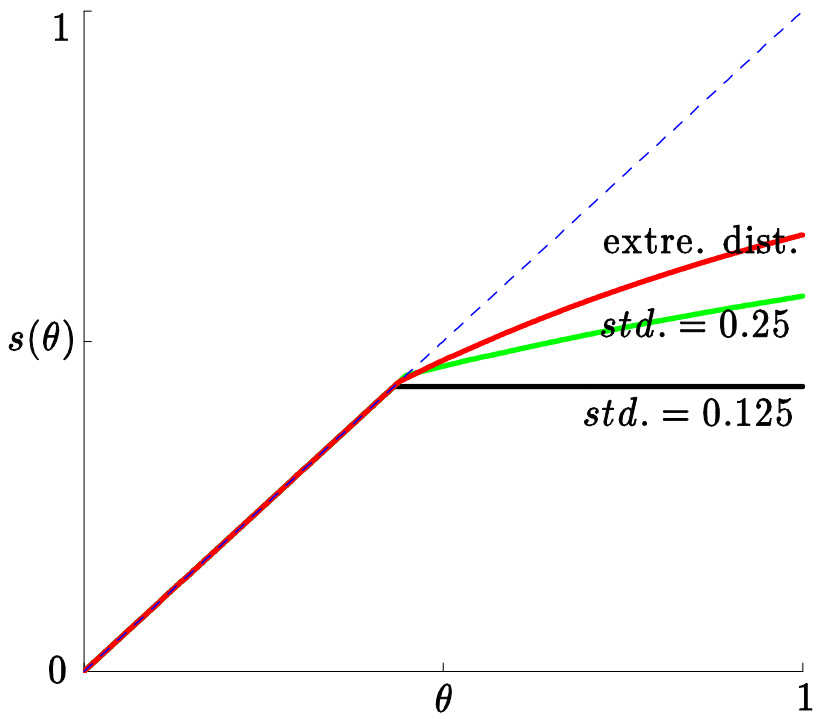


Positive NPV

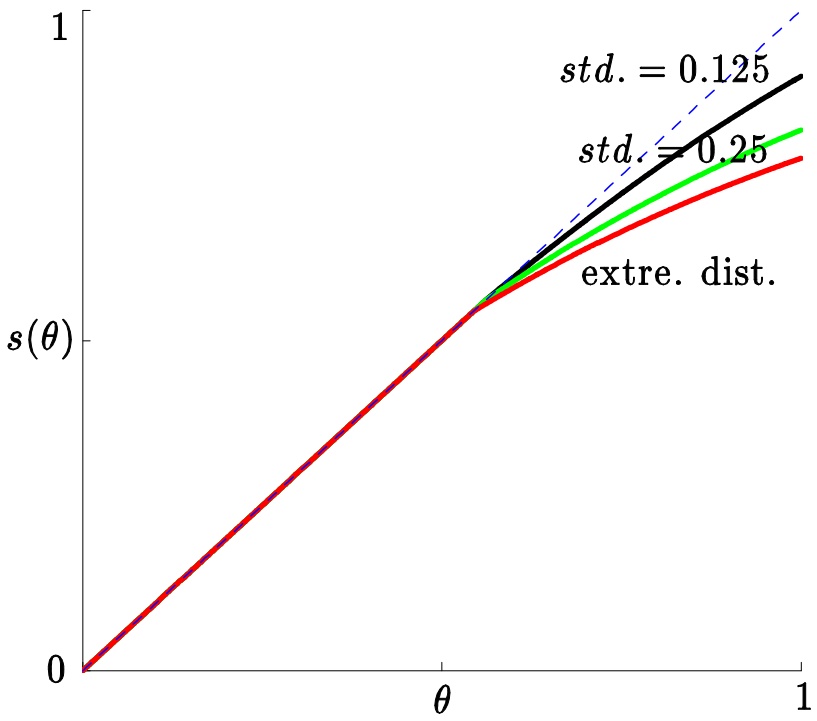


Negative NPV

Change of Uncertainty : Positive vs. Negative NPV



Positive NPV



Negative NPV