Information in Sequential Evaluations: the Good and the Bad

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Motivation

- Many risky opportunities are offered *sequentially* to *multiple* parties *until one takes it*:
    - The seller of an asset can contact many interested buyers
    - Consumers – home buyers have many banks to apply to for credit
    - Entrepreneurs contact many VCs or angel investors for (seed) funding
- Whoever gets an offer must *evaluate* whether opportunity is profitable or not

  So: more information $\longrightarrow$ better judgements of opportunity $\longrightarrow$ better off evaluators?
- But: the evaluators also face an **adverse selection** problem:

  How many were offered and rejected the opportunity before it was my turn?
- **Information shapes adverse selection:**

  Maybe: more information $\longrightarrow$ more adverse selection $\xrightarrow{??}$ worse off evaluators?

Motivation

When does more information leave evaluators better off? (read: improve selection quality)

Important policy question, one example is credit scoring in banking.

- Banks want better statistical scoring models for competitiveness and quality lending:
  - Do not necessarily know *why* & *how* models work: neural networks, SVMs...
- Regulators want them to have & use better information, too!

Basel II: allowed Internal Ratings Based systems instead of Standardised Scoring to:

"provide a more risk-sensitive approach to measuring credit risk"

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Basel III after the subprime mortgage crisis:

"CVA is a complex risk ... cannot be modelled by banks in a robust and prudent manner. The revised framework removes the use of an internally modelled approach ..."

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- Banks want better statistical scoring models for competitiveness and quality lending:
  - Do not necessarily know *why* & *how* models work: neural networks, SVMs...
- Regulators want them to have & use better information, too! But sometimes not!

Banks disagree with Basel III... **for the same reason**:

"[Internal assessments] by banks allow for the most accurate measurement of risk ... Relying on regulators' assessments ... will be rough approximations at best ... a major step backwards"

Kenneth Bentsen, CEO of Global Financial Markets Association

The Model

- APPLICANT with unknown quality $\theta \in \{L, H\}$ **seeks approval** from **one evaluator**.
  - Prior belief $\rho \in (0, 1)$ that applicant is **born** with *High* quality.
- He sequentially visits $n \geq 2$ EVALUATORs, at random order τ.
  - τ is a permutation of $\{1, 2, ..., n\}$, chosen **privately** and **uniformly at random** by applicant.
- EV **approves** $\longrightarrow$ payoff $\mathbb{1}\{\theta = H\} - c$, $c \in (0, 1)$. Game ends, other EV.s get 0 payoff.

  EV **rejects** $\longrightarrow$ 0 payoff. Applicant keeps applying. If no EV left $\rightarrow$ game ends.

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- EVs **do not know** θ or τ. But: receive **private IID signals** x about **quality** θ:

$$x \in \{s_1, s_2, ..., s_m\} \subset [0,1] \qquad x \mid \theta \overset{\text{IID}}{\sim} p_\theta \qquad s_i = \frac{p_H(s_i)}{p_H(s_i) + p_L(s_i)} < s_{i+1}$$

- **Equilibrium: symmetric** strategy and *interim* belief profile (σ^*, ψ^*) for EVs such that:
  - $\psi^* = \mathbb{P}(\theta = H \mid \text{applicant visited me})$ is *consistent* with strategy profile σ^*
  - $\sigma^* : \{s_1, s_2, ..., s_m\} \to [0,1]$ **optimal** given ψ^*; approve when $\mathbb{P}(\theta = H \mid x, \psi) > c$

Main Question and Takeaway

How does more information affect evaluators' equilibrium payoffs?

- Synonymous to **selection quality**: $\uparrow$ eqm. payoffs when $\downarrow$ false positives & negatives.
- **Main problem:** More information affects adverse selection (ψ^*). This indirect effect might backfire on selection quality.
- **Main result:** Characterise effect of arbitrary **Blackwell improvements** of EVs signals.
- **Main takeaway:** Depends on the **kind** of improvement. Roughly:
  - $\uparrow$ **approval confidence**: **good!**
  - $\uparrow$ **rejection confidence**: eventually **bad**

affect different applicants

$\downarrow$

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- Giving EVs information about **order** τ
- EV makes *take-it-or-leave-it* price offer to applicant
- EVs compete on **application costs**

ask me after talk!

Interim Beliefs and Equilibria

- Prior belief ρ that applicant is born with $\theta = H$ is a primitive.
- Interim belief $\psi = \mathbb{P}\left(\theta = H \mid \text{applicant visited me}\right)$ is **endogenous**:
  - What is the chance applicant visited me after k rejections?
  - What do those rejections mean about his quality?
- ψ is *consistent* with the strategy σ for all evaluators, iff:

$$\psi = \frac{\rho \times \sum_{k=1}^{n} r_H(\sigma)^k}{\rho \times \sum_{k=1}^{n} r_H(\sigma)^k + (1-\rho) \times \sum_{k=1}^{n} r_L(\sigma)^k} \qquad \text{where} \quad r_\theta(\sigma) = 1 - \sum_{i=1}^{m} p_\theta(s_i)\sigma(s_i)$$

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Interim Beliefs and Equilibria

- Endogeneity means existence, number, or properties of equilibria are not automatic.

Proposition

Let $p_H \neq p_L$. The set of equilibrium strategies is non-empty and compact, and pointwise totally ordered. Furthermore:

1. all equilibrium strategies are monotone; $\sigma^*(s_i) > 0$ implies $\sigma^*(s_{i+1}) = 1$.
2. all equilibria exhibit adverse selection : $\psi^* \leq \rho$.

- Compact and totally ordered $\rightarrow$ we can talk about:
  - the *highest* (most embracive) equilibrium,
  - the *lowest* (most selective) equilibrium.

Interim Beliefs and Equilibria

- (the sum of) Evaluators' equilibrium payoffs:

$$\Pi(\sigma) := \rho \times (1-c) \times \mathbb{P}\left(\text{eventually approved} \mid \theta = H, \sigma\right) + \\ -(1-\rho) \times c \times \mathbb{P}\left(\text{eventually rejected} \mid \theta = L, \sigma\right)$$

- What do *selective* and *embracive* equilibria mean for payoffs?
- Different virtues: *selective* $\rightarrow$ filter *Low* quality approvals but miss out *High* quality
  embracive $\rightarrow$ secure *High* quality but overlook *Low* quality approvals
- Nonetheless, trade-off is always resolved in favour of *selective equilibria*:

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Proof Sketch:

- Take eqm. strategy σ^*, and consider *marginally more embracive* σ^ε: $||\sigma^\varepsilon - \sigma^*|| = \varepsilon$
- Fix the signals all EVs would see if app. visited them all: $\{x_1, x_2, ..., x_n\}$.
- Only app. whose outcome changes: rejected by all under σ^*, approved by some under σ^ε.
- If ε is small, he was rejected by all under σ^*, approved by one under σ^ε.
- Bad news: that last evaluator gets negative expected payoffs
  - In eqm., would like to reject him under **suspicion** of adverse selection
  - Approving him when he is the **most adversely selected** cannot help

Interim Beliefs and Equilibria

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- If ε is small, he was rejected by all under σ^*, approved by one under σ^ε.
- Bad news: that last evaluator gets negative expected payoffs
- Last step: payoffs are **single crossing** in embraciveness; where $\sigma'' > \sigma' > \sigma$

$$\Pi(\sigma') \leq \Pi(\sigma) \implies \Pi(\sigma'') \leq \Pi(\sigma')$$

Information and Equilibrium Payoffs

$$\Pi(\sigma) := \rho \times (1-c) \times \mathbb{P}\left(\text{eventually approved} \mid \theta = H, \sigma\right) +$$
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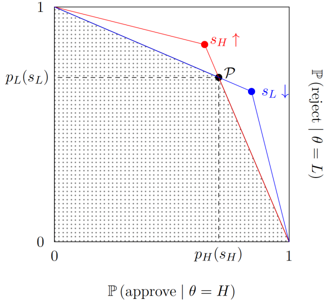
- With *one* evaluator, **Blackwell more informative** signal $\overset{(\Longleftarrow)}{\Longrightarrow} \uparrow$ payoffs for all c, ρ
- Reason: affords lower false positives & negatives
- Example: binary signal. $S = \{s_1, s_2\}$.



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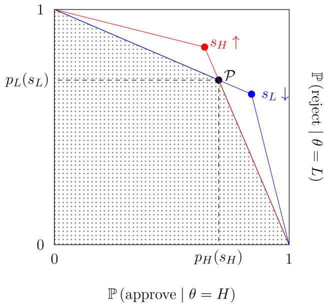
- With *one* evaluator, **Blackwell more informative** signal $\overset{(\Longleftarrow)}{\Longrightarrow}$ $\uparrow$ payoffs for all c, ρ
- Reason: affords lower false positives & negatives
- Example: binary signal. $S = \{s_L, s_H\}$. A Blackwell improvement is $\downarrow s_L$ or $\uparrow s_H$.



Information and Equilibrium Payoffs

- What could go wrong? Let's rewrite EV i's payoff $\pi_i \left(= \frac{\Pi}{n}\right)$:

$$\pi_i(\sigma) = \mathbb{P}\left(\text{applicant visits } i\right)$$
$$\times \left[\psi \times (1-c) \times \mathbb{P}\left(i \text{ approves} \mid \theta = H\right) + (1-\psi) \times (-c) \times \mathbb{P}\left(i \text{ approves} \mid \theta = L\right)\right]$$

- The blue adverse selection terms are outside EV i's control: depend on others' strategies
- EVs do not take adverse selection they impose to others into account
- Maximising individual selection quality $\neq$ maximising **overall** selection quality

Binary Signals: Information and Eqm. Payoffs

- Start from **binary signals**: main intuition and building block to full characterisation
- $x \in S = \{s_L, s_H\}$ **more informative** when $s_L \downarrow$: **stronger evidence for *Low* quality**
  and $s_H \uparrow$: **stronger evidence for *High* quality**

Theorem

Let EVs have a binary signal, $x \in S = \{s_L, s_H\}$. Their equilibrium payoffs in the most selective (embracive) equilibria are weakly:

- increasing with stronger evidence for $\theta = H$ ($\uparrow s_H$),
- increasing with stronger evidence for $\theta = L$ ($\downarrow s_L$) when s_L is above a threshold,
- decreasing with stronger evidence for $\theta = L$ ($\downarrow s_L$) when s_L is below that threshold.

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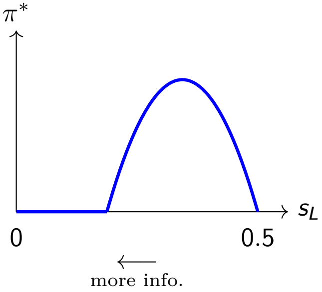
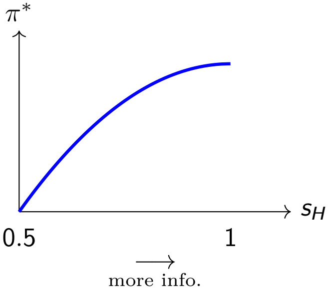
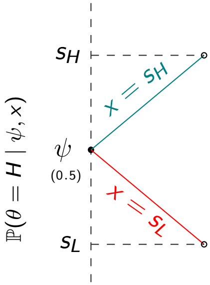




Binary Signals: Information and Eqm. Payoffs

Sketch Proof:

- Consider decreasing s_L marginally. How to implement this Blackwell improvement?
- Fix strategies [handle in actual proof]: approve with high signal & reject with low signal



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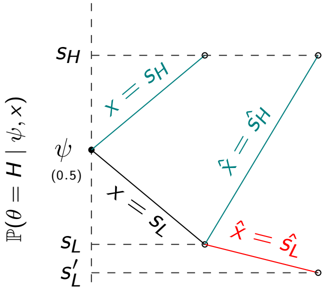

- Like before, fix signal pairs $(x, \hat{x})$ all EVs would see.
- We created **marginal admits**: rejected by all in old signal structure, approved by some in new.
- All info. on marginal admits' quality $\longrightarrow$ how many $\hat{x} = \hat{s_H}$ signals.

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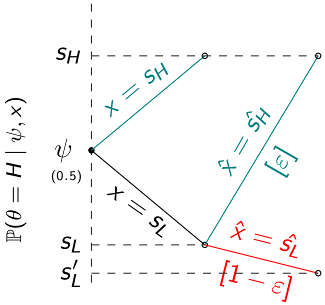

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- We created **marginal admits**: rejected by all in old signal structure, approved by some in new.
- All info. on marginal admits' quality $\longrightarrow$ how many $\hat{x} = \hat{s}_H$ signals. **Answer: only one!**
- For **marginal** decrease in s_L, $\mathbb{P}(\hat{x} = \hat{s}_H) \propto \varepsilon \to 0$.
- **Multiple** $\hat{x} = \hat{s}_H$ has negligible probability.

Binary Signals: Information and Eqm. Payoffs

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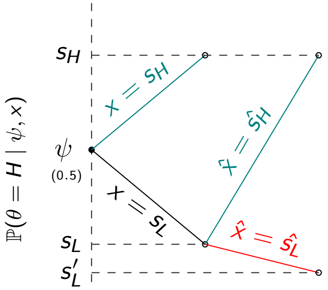


- Whether the **marginal admit** is profitable:

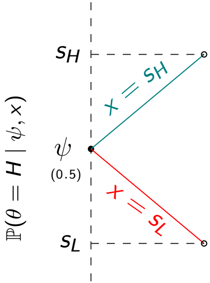
$$\underbrace{\frac{\rho}{1-\rho}}_{\text{prior}} \times \underbrace{\left(\frac{s_L}{1-s_L}\right)^{n-1}}_{n-1 \text{ low signals}} \times \underbrace{\frac{s_H}{1-s_H}}_{\text{the only high signal}} \lessgtr \underbrace{\frac{c}{1-c}}_{\text{approval cost}}$$

- **Lesson:** Whenever there is a **threat** of adverse selection, stronger evidence for $\theta = L$ hurts.

Binary Signals: Information and Eqm. Payoffs

Sketch Proof:

- Now consider increasing s_H marginally. How to implement this Blackwell improvement?
- Fix strategies as before: approve with high signal & reject with low signal



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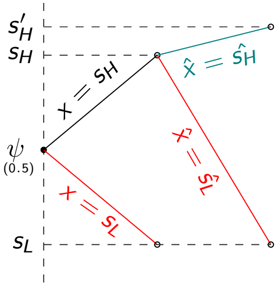


- This time **marginal rejects**: approved by some before, rejected by all now.
- All EVs must have seen low signals.
- **Marginal reject** is always good to push out:

$$\underbrace{\frac{\rho}{1-\rho}}_{\text{prior}} \times \underbrace{\left(\frac{s_L}{1-s_L}\right)^n}_{n \text{ low signals}} < \underbrace{\frac{c}{1-c}}_{\text{approval cost}}$$

[actual proof: show this is the only relevant case]

Binary Signals: Information and Eqm. Payoffs

- Main lesson from Theorem:
  - $s_H \uparrow$ benefits EVs $\longrightarrow$ marginal rejects
  - $s_L \downarrow$ hurts EVs **when $\mathbf{s_L}$ is below a threshold** $\longrightarrow$ marginal admits
- A candidate for the threshold came from sketch proof:

$$\underbrace{\frac{\rho}{1-\rho}}_{\text{prior}} \times \underbrace{\left(\frac{s_L^{\mathrm{as}}}{1-s_L^{\mathrm{as}}}\right)^{n-1}}_{n-1 \text{ low signals}} \times \underbrace{\frac{s_H}{1-s_H}}_{\text{the only high signal}} = \underbrace{\frac{c}{1-c}}_{\text{approval cost}}$$

- s_L^{as}: strongest evidence for $\theta = L$ where **adverse selection is not a threat**.
- **Marginal admit hurts** when $s_L < s_L^{\mathrm{as}}$.

Binary Signals: Information and Eqm. Payoffs

- The actual threshold depends more subtly on equilibrium dynamics.
- EVs might be stuck in eqa. where all applicants are approved when info. is too weak:

$$\underbrace{\frac{\rho}{1-\rho}}_{\text{prior}} \times \underbrace{\left(\frac{s_L^{\text{mute}}}{1-s_L^{\text{mute}}}\right)}_{\text{one low signal}} = \underbrace{\frac{c}{1-c}}_{\text{approval cost}}$$

when $s_L \geq s_L^{\text{mute}}$, *always* an eqm: approve all $\rightarrow$ no adverse selection $\rightarrow$ approve all

Proposition

Let EVs have a binary signal $x \in \{s_L, s_H\}$. The threshold below which lower s_L weakly decreases their equilibrium payoffs is:

- $s_L^{\text{as}} \geq \min\{s_L^{\text{mute}}, s_L^{\text{as}}\}$ for the most embracive equilibrium.
- $s_L^{\text{as}} \geq s_L^{\dagger} \geq \min\{s_L^{\text{mute}}, s_L^{\text{as}}\}$ for the most selective equilibrium.

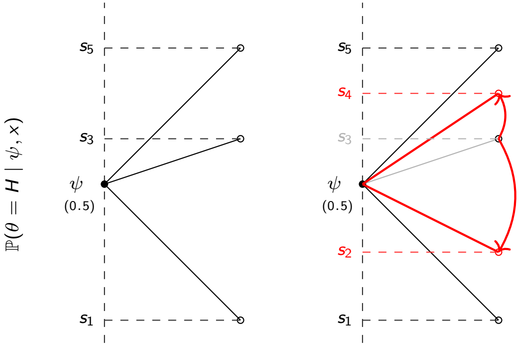
General Blackwell Improvements and Eqm. Payoffs

- In many settings, EVs of risky opportunities have richer signal structures:
  - Analyst reports for stock traders: "Strong Sell", "Sell", "Buy", "Strong Buy".
  - Consumer credit scoring: multi-class scorecard might only eventually be aggregated to binary.
- Important to generalise from binary to Blackwell improvements of any discrete signal.
- Previously: auxiliary signal spreads belief further after initial $x = s_H$ or $x = s_L$
- Now generalise this idea: **local mean preserving spreads**.

General Blackwell Improvements and Eqm. Payoffs

Take two signals, $x \mid \theta \overset{IID}{\sim} p_\theta$ and $x' \mid \theta \overset{IID}{\sim} p'_\theta$. Joint support $S \cup S' = \{s_1, s_2, ..., s_M\}$.

x' differs from x by a local MPS at s_i if:



- p_θ places no mass at s_{i-1} or s_{i+1}.
- p'_θ places no mass at s_i.
- p_θ and p'_θ place equal mass to all points except $\{s_{i-1}, s_i, s_{i+1}\}$.
- *p and p' have equal normalised means*:

$$\sum_{j=1}^{M} s_j \times \left(\frac{p_L(s_j) + p_H(s_j)}{2}\right) = \sum_{j=1}^{M} s_j \times \left(\frac{p'_L(s_j) + p'_H(s_j)}{2}\right)$$

General Blackwell Improvements and Eqm. Payoffs

Local mean preserving spreads *characterise* Blackwell improvements:

Remark

If x' differs from x by a local MPS, x' is *Blackwell more informative than* x. Furthermore, if x' is *Blackwell more informative than* x, there is a finite sequence $x_1, x_2, ..., x_k$ such that:

- $x_1 = x$ and $x_k = x'$,
- x_{i+1} differs from x_i by a local MPS.

- Only *slight* refinement of classic Rothschild and Stiglitz, 1970 result.
- I will characterise the effect of a local MPS.

General Blackwell Improvements and Eqm. Payoffs

One more definition before result:

For a fixed signal x and strategy σ, *adverse selection poses a threat at signal s if*:

$$\underbrace{\frac{\rho}{1-\rho}}_{\text{prior}} \times \underbrace{\left(\frac{r_H(\sigma)}{r_L(\sigma)}\right)^{n-1}}_{n-1 \text{ past rejections}} \times \underbrace{\frac{s}{1-s}}_{\text{last signal is } s} \leq \underbrace{\frac{c}{1-c}}_{\text{approval cost}}$$

Theorem

Let x' differ from x by a local MPS at s_i. EVs' expected payoffs under the most embracive (selective) equilibrium are:

1. *weakly higher* under x' if $x = s_i$ leads to approvals under σ; $\sigma(s_i) = 1$,
2. *weakly lower* under x', if:
    1. $x = s_i$ leads to rejections under σ; $\sigma(s_i) = 0$, and
    2. adverse selection poses a threat at signal s_{i+1}, for signal structure x and strategy σ.

General Blackwell Improvements and Eqm. Payoffs

- Local MPS necessary, helps pin down equilibrium response to spread.
- Knowing when a spread must be harmful requires knowing equilibrium structure
- Unpleasant: WHY?
- We can offer a stronger sufficient condition that relies only on the local MPS performed:

Proposition

Let x' differ from x by a local MPS at s_i. EVs expected payoffs in the most selective equilibrium are lower under x' whenever s_i is a rejection signal under x and:

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Proposition

Let x' differ from x by a local MPS at s_i. EVs expected payoffs in the most selective equilibrium are lower under x' whenever ~~s_i is a rejection signal under x~~ and:

a fortiori: $s_L < s_L^{\text{mute}}$:

$$\frac{\rho}{1-\rho} \times \left(\frac{s_i}{1-s_i}\right)^{n-1} \times \frac{s_{i+1}}{1-s_{i+1}} \leq \frac{c}{1-c}$$