

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 & fin. derivative can contact many interested buyers
 - Debt seekers 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: these 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 info. 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”

“reward stronger and more accurate risk measurement”

“Regulation Guide: An Introduction”, *Moody's Analytics*

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Basel III banned it back, 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 ...”

“High-Level Summary of Basel III Reforms”, [Bank of Intl. Settlements](#)

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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 $\{1, 2, \dots, n\}$, 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 :

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

- **Equilibrium:** symmetric strategy and interim belief profile (σ^*, ψ^*) for EVs such that:
 - $\psi^* = \mathbb{P}(\theta = H \mid \text{applicant visited me})$ – **consistent** with strategy profile σ^*
 - $\sigma^* : \{s_1, s_2, \dots, s_m\} \rightarrow [0, 1]$ – **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 with **selection quality**: eqm. payoffs \uparrow when false positives & negatives \downarrow .
- **Main problem**: More information affects **adverse selection**; i.e. the interim belief ψ^* .
This indirect effect might backfire on payoffs – selection quality.
- **Main result**: Characterise effect of arbitrary **Blackwell improvements** of EVs signals.
- **Main takeaway**: Effect on payoffs depends on the **kind** of improvement. Roughly:
 - higher **approval confidence**: **good!**
 - higher **rejection confidence**: **eventually bad**

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} affect different applicants
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have different payoff effects
 - 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 $\psi = \mathbb{P}(\theta = H \mid \text{applicant visited me})$ 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:

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

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where $r_\theta(\sigma) = 1 - \underbrace{\sum_{i=1}^m p_\theta(s_i) \sigma(s_i)}_{\text{rejection prob. given quality}}$

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 embrative**) equilibrium,
 - the *lowest* (**most selective**) equilibrium.

Interim Beliefs and Equilibria

- What do *selective* and *embrative* equilibria mean for payoffs?
- (the sum of) Evaluators' equilibrium payoffs:

$$\begin{aligned}\Pi(\sigma) := & \rho \times (1 - c) \times \mathbb{P}(\text{one EV approves} \mid \theta = H, \sigma) + \\ & -(1 - \rho) \times c \times \mathbb{P}(\text{all EVs reject} \mid \theta = L, \sigma)\end{aligned}$$

- Different virtues: **selective** \rightarrow filter *Low* quality approvals but miss out *High* quality
embrative \rightarrow secure *High* quality but overlook *Low* quality approvals

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Proposition

Let σ^* be an eqm. strategy and σ^{**} be a *more embrasive* eqm. strategy; $\sigma^{**} > \sigma^*$.

Then: $\Pi(\sigma^{**}) \leq \Pi(\sigma^*)$

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Proof Sketch:

- Take eqm. strategy σ^* , and consider *marginally more embrative* σ^ε : $\|\sigma^\varepsilon - \sigma^*\| = \varepsilon$
- Fix the signals all EVs would see if app. visited them all: $\{x_1, x_2, \dots, x_n\}$.
- Only app. whose outcome changes: **rejected by all under σ^* , approved by some under σ^ε** .
- If ε is small, he was a.s. **rejected by all under σ^* , approved by one under σ^ε** .
- Bad news: **approving is suboptimal for this last EV**
- Last step: payoffs are **single crossing** in embraciveness; where $\sigma'' > \sigma' > \sigma$:

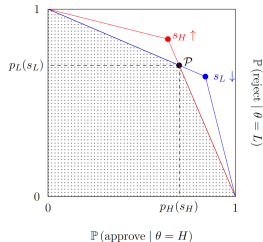
$$\Pi(\sigma') \leq \Pi(\sigma) \implies \Pi(\sigma'') \leq \Pi(\sigma')$$

Information and Equilibrium Payoffs

How do payoffs in these equilibria change with more information?

$$\begin{aligned}\Pi(\sigma) := & \rho \times (1 - c) \times \mathbb{P}(\text{one EV approves} \mid \theta = H, \sigma) + \\ & -(1 - \rho) \times c \times \mathbb{P}(\text{all EVs reject} \mid \theta = L, \sigma)\end{aligned}$$

- With *one* evaluator, **Blackwell more informative signal** (\Leftrightarrow) \uparrow payoffs for all c, ρ
- Reason: affords lower false positives & negatives



Example: binary signal.

$$S = \{s_1, s_2\}$$

A Blackwell imp. is:

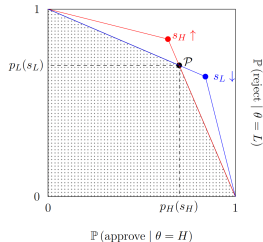
$$\downarrow s_1 \quad \uparrow s_2$$

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- With *one* evaluator, **Blackwell more informative signal** $(\Leftarrow \Rightarrow)$ \uparrow payoffs for all c, ρ
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Example: binary signal.

$$S = \{s_L, s_H\}$$

A Blackwell imp. is:

$$\downarrow s_L \quad \uparrow s_H$$

Information and Equilibrium Payoffs

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

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

- 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

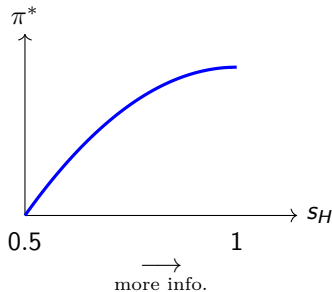
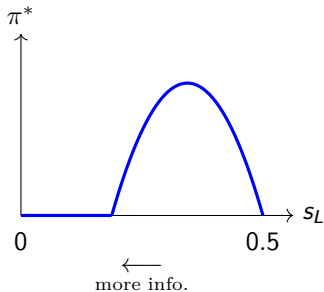
Let EVs have a binary signal, $x \in S = \{s_L, s_H\}$. Their equilibrium payoffs in the most selective (embrative) equilibria are weakly:

- 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.

Binary Signals: Information and Eqm. Payoffs

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

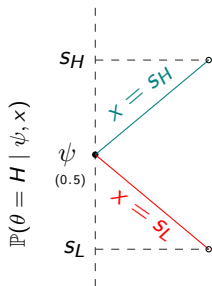
Theorem:



Binary Signals: Information and Eqm. Payoffs

Sketch Proof:

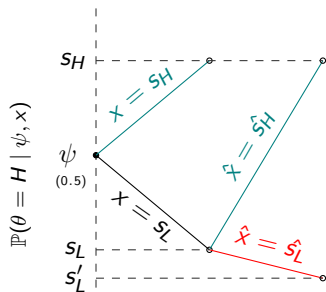
- Consider **decreasing s_L marginally**. How to implement this Blackwell improvement?
- Fix strategies [handle in actual proof]: **approve with high signal** & **reject with low signal**



Binary Signals: Information and Eqm. Payoffs

Sketch Proof:

- Consider **decreasing s_L marginally**. How to implement this Blackwell improvement?
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- Construct an **auxiliary signal \hat{x}** .

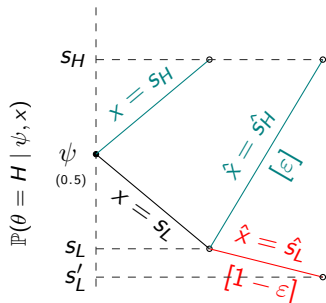


- Like before, fix signal pairs (x, \hat{x}) all EVs would see.
- We created **marginal admits**: rejected by all in old signal structure, approved by some in new.
- All info. on marginal admits' quality \rightarrow how many $\hat{x} = \hat{s}_H$ signals.

Binary Signals: Information and Eqm. Payoffs

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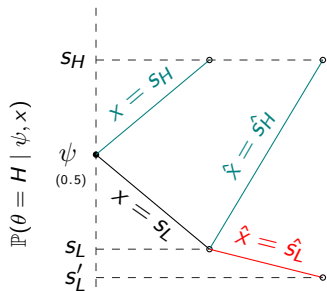


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- We created **marginal admits**: rejected by all in old signal structure, approved by some in new.
- All info. on marginal admits' quality \rightarrow how many $\hat{x} = \hat{s}_H$ signals. **Answer: only one!**
- For **marginal** decrease in s_L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

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



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

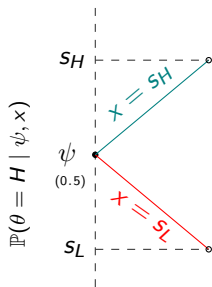
$$\underbrace{\frac{\rho}{1-\rho}}_{\text{prior}} \times \underbrace{\left(\frac{s_L}{1-s_L}\right)^{n-1}}_{n-1 \text{ low signals}} \times \underbrace{\frac{s_H}{1-s_H}}_{\text{the only high signal}} \leq \underbrace{\frac{c}{1-c}}_{\text{approval cost}}$$

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

Binary Signals: Information and Eqm. Payoffs

Sketch Proof:

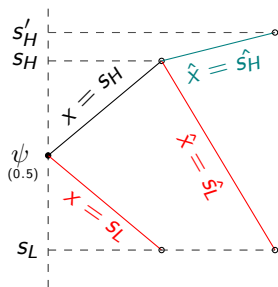
- Now consider **increasing s_H marginally**. How to implement this Blackwell improvement?
- Fix strategies as before: **approve with high signal** & **reject with low signal**



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**
- Construct an **auxiliary signal \hat{x}** .



- 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 \rightarrow marginal rejects
 - $s_L \downarrow$ hurts EVs **when s_L is below a threshold** \rightarrow marginal admits
- A candidate for the threshold came from sketch proof:

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

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

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

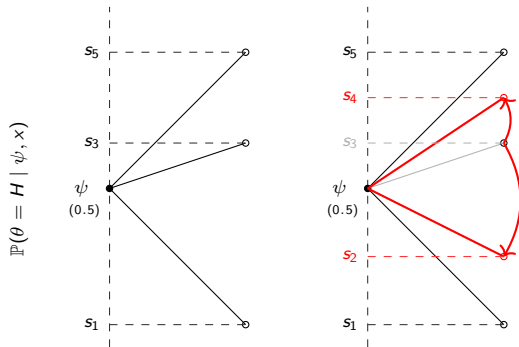
General Blackwell Improvements and Eqm. Payoffs

- 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, $x \mid \theta \stackrel{IID}{\sim} p_\theta$ and $x' \mid \theta \stackrel{IID}{\sim} p'_\theta$. Joint support $S \cup S' = \{s_1, s_2, \dots, s_M\}$.

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, \dots, 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 embrative (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: $s_L < s_L^{\text{mute}}$:

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

Related Literature