

Ordonnancement optimal des pages proposées par un moteur de recherche

Pierre L'Ecuyer



Patrick Maillé, Nicolás Stier-Moses, Bruno Tuffin



Search engines

- ▶ Major role in the Internet economy
- ▶ most popular way to reach web pages
- ▶ 20 billion requests per month from US home and work computers only

Search engines

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For a given (set of) keyword(s), a search engine returns a ranked list of links: the **organic results**.

Organic results are supposed to be based on **relevance only**

Is this true?

Each engine has its own formula to measure (or estimate) relevance. May depend on user (IP address), location, etc.

Refine your search for specialized s work venge 52

Categories

All

Sporting Goods

Bicycles

Condition

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Price

\$ to \$ >>

Format

see all

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Auction (0)

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1-16 of 83 results for Books : "Pierre l'ecuyer"

Sort by Relevance ▾

Show results for

< Any Category

Books

- Histoire et Sciences humaines (1)
- Sociology (1)
- Networking & Cloud Computing (10)
- Programming (30)
- Computers & Technology (55)
- Hardware (9)
- Algorithms Textbooks (6)
- Algorithms (14)
- Textbooks (56)

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Author

- Mohamed Cherkaoui
- Raymond Boudon
- Thierry Martin

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- Coming Soon

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- 10% Off or More (70)
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by Pierre L' Ecuyer

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Results for "Pierre L'Ecuyer stochastic" in Books [See all 10 results...](#)

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8 results for Books : "gilles brassard algorithmics"

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Books

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- Logic (1)
- Computer Science (1)
- Software (1)
- Programming Algorithms (1)
- Programming (1)
- Computers & Technology (1)
- Discrete Mathematics (1)
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- ★★★☆☆ & Up (2)
- ★★☆☆☆ & Up (2)

Condition

Collectible (1)

New (8)



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by Gilles Brassard and Paul Bratley

Hardcover

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Paperback

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Fundamentals of Algorithmics Aug 20, 1995

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2 Rue Leblanc



Gîte Les Colibris B & B

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80 SAINTE-ANNE RUE



Gîte Nature et Pinceaux

\$110

No reviews · 4-star hotel

French country style in an elegant rural inn, with free WiFi & gardens with a fire pit & hammocks.

33 rue du Nordet



Gîte la Chambre des Maîtres

 Visit
website

2 reviews · 4-star hotel

Casual rooms in a relaxed B&B with a seasonal outdoor pool, plus a guest lounge with a fireplace.



À La Chouette



4-star hotel

\$115

per night

Address: 2 Rue Leblanc, Baie-Saint-Paul, QC G3Z 1W9

Website

Directions

Phone: (418) 435-3217

A 5-minute walk from the town centre, this relaxed B&B in a quaint clapboard cottage is a 6-minute walk from the Musée D'Art Contemporain De Baie St-Paul modern art museum and 1.8 km from ... [More](#)

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www.youtube.com/watch?v=tb-sqWJyWqA

 Mar 31, 2012 - Uploaded by CIRaport ca
 Skinny Indian? What part of Brazeau is skinny? Secondly please take a good look at Patrick Brazeau, if he is ...
Justin Trudeau -- Patrick Brazeau Charity Boxing Match ...
www.youtube.com/watch?v=XuSpZ3_5pTc

 Apr 1, 2012 - Uploaded by FactPointVideo
 Justin Trudeau -- Patrick Brazeau Charity Boxing Match -- English ... they went under, I love watching the ...
Trudeau vs Brazeau BOXING FOR CANCER (Full fight ...
<https://www.youtube.com/watch?v=FYWIZMhaLE>

 Apr 1, 2012 - Uploaded by Reasoning Conspiracy
 ... link <http://www.sunnewsnetwork.ca/video/1540728713001>
 Watch the ... Patrick Brazeau and Justin ...
Meet Justin Trudeau: The Tattooed, Boxing New Canadian ...
www.nbcnews.com/video/meet-justin-trudeau-the-t...

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 Meet Justin Trudeau: The Tattooed, Boxing New Canadian Prime Minister ... Stunning Video Shows Qantas ...
**Justin Trudeau vs Patrick Brazeau Le combat de boxe ...**
www.youtube.com/watch?v=go7nf6xwfyA

 Mar 31, 2012 - Uploaded by LP - Mma Nouvelles
 Justin Trudeau vs Patrick Brazeau Le combat de boxe Justin Trudeau -- Patrick Brazeau Charity Boxing ...
Justin Trudeau Boxing Match Weigh In With Senator Patrick ...
www.youtube.com/watch?v=M0e9D2rBN9w

 Mar 28, 2012 - Uploaded by althiaraj
 Liberal MP Justin Trudeau meets his competitor Conservative Senator Patrick Brazeau for a weigh in before ...
Justin Trudeau Boxing - YouTube
www.youtube.com/watch?v=JLQWA35er3g

Aug 6, 2015 - Uploaded by Alex Guibord

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Justin Trudeau Beats Patrick Brazeau In Charity Boxing Match

▶ 01:29 - HD - 2012-03-31 - Par eCanadaNow Breaking News

 YouTube - 6 000+ vues



Justin Trudeau Boxing Weigh-In With Senator Patrick ...

⇨ 04:20 - 2012-03-28 - Par | By

The Huffington Post



Justin Trudeau vs. Patrick Brazeau Boxing Match p1

▶ 12:03 - HD - 2012-03-31 - Par CIReport ca

 YouTube - 22 000+ vues



Justin Trudeau -- Patrick Brazeau Charity Boxing Match ...

▶ 16:14 - HD - 2012-04-01 - Par FactPointVideo

 YouTube - 101 000+ vues



Trudeau Admits Wife Thought He Might Lose Boxing Match

⇨ 00:26 - 2012-10-16 - Par HuffPost Canada Studios

Aol.On - 10 000+ vues



Trudeau vs Brazeau BOXING FOR CANCER (Full fight)

▶ 11:26 - 2012-04-01 - Par Reasoning Conspiracy

 YouTube - 25 000+ vues



Justin Trudeau gets some boxing practice in ahead of first ...

▶ 01:35 - 2015-08-06 - Par Global News

 YAHOO! NEWS



Justin Trudeau and Patrick Brazeau - bet after boxing ...

▶ 09:50 - 2015-07-21 - Par Marksminstrel

 Dailymotion - vues 16 fois



Justin Trudeau Works Out in Boxing Ring Ahead of Debate

⇨ 01:12 - 2015-08-06 - Par Canadian Press

Aol.On

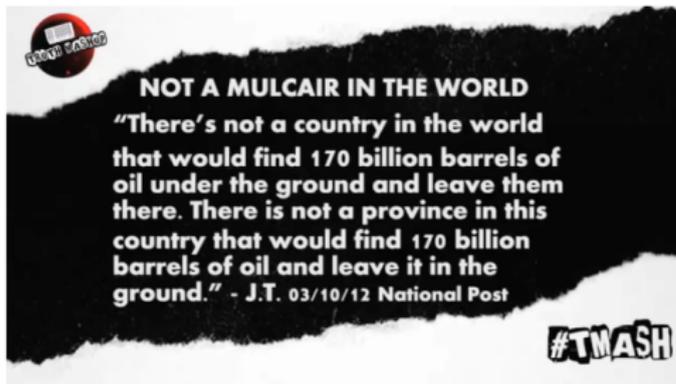
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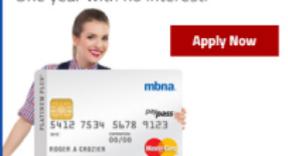
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297 vues



Eva Simons - I Don't Like You



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Video: Evo Morales caught kneeling player in groin during ...



www.telegraph.co.uk > ... > South America > Bolivia ▾
Oct 5, 2010

Evo Morales, the Bolivian president, has been caught on camera kneeling an opposing player in the groin ...



Bolivian president Morales plays football for UN - YouTube



www.youtube.com/watch?v=uHIT3T9o6GI

Sep 27, 2013 - Uploaded by AFP news agency

President of Bolivia Evo Morales during a soccer match at a park near the UN on the sidelines of the 68th ...

Bolivian President kicks man in bollocks (in football match ...



<https://www.youtube.com/watch?v=5XkbNUix5Bo>

Oct 6, 2010 - Uploaded by TrashTVChannel

Bolivian president Evo Morales caught on camera knee-ing opponent (Daniel Gustavo Cartagenam) in the ...

Ahmadinejad plays football with Bolivian President Evo ...



www.youtube.com/watch?v=ragk2EPqww ▾

Oct 27, 2010 - Uploaded by sherlock72

During a visit of Bolivian President Evo Morales to Iran , he played a friendly football game with Iranian ...

Bolivian president Morales plays football for UN - Video ...



www.dailymotion.com/video/x158t77_bolivian-presid...

Sep 27, 2013

President of Bolivia Evo Morales during a soccer match at a park near the UN on the sidelines of the 68th ...



Bolivia: Watch Evo Morales play against ex-Real Madrid ...



<https://www.youtube.com/watch?v=v9oz0vD2U4>

Oct 8, 2014 - Uploaded by Ruptly TV

Video ID: 20141008-057 M/S Evo Morales and former Real Madrid ... Bolivian President Evo Morales ...

Bolivian President Morales plays in friendly football match ...



www.youtube.com/watch?v=PUxWjVVGLOI

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Bolivian President Evo Morales walking onto pitch in Cadiz stadium 2 ... Bolivian President Morales plays ...

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<https://www.youtube.com/watch?v=0OIdGQQ0L8>

Images for barack obama basketball video



Barack Obama's basketball fail - YouTube

<https://www.youtube.com/watch?v=gmTfKPx1Cug>
1 Apr 2013 - 1 min - Uploaded by The Telegraph



putin judo video

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'Judo Knight' Putin shows off martial arts skills in wrestling ...



<https://www.youtube.com/watch?v=0lxMglj8LuM>
Dec 23, 2010 - Uploaded by RT
Prime Minister Vladimir Putin has taken another step to boost his charisma by ... Bodyguard face-off video ...

Putin's Judo - YouTube



https://www.youtube.com/watch?v=dYIDQ_t_HQ
Apr 5, 2012 - Uploaded by strawisinthetack
Vladimir Putin has a black belt in the martial art and has competed at a high ... One day...a dream face off ...

Let's Learn Judo with Vladimir Putin (2008) - YouTube



<https://www.youtube.com/watch?v=162myM2fJE>
Nov 7, 2012 - Uploaded by Putinery
... Russian President Vladimir Putin shares his favourite judo moves. ... Let's Learn Judo with Vladimir ...

Putin may join Russian Olympic judo team - YouTube



<https://www.youtube.com/watch?v=2c3wzbyikw>
Dec 20, 2009 - Uploaded by RT
The Russian Judo Olympic team may have a new member. ... Russia's Got Talent: Extra video of Putin ...

Putin practices judo - No comment - YouTube



<https://www.youtube.com/watch?v=V5z5UAtCvgE>
Dec 21, 2009 - Uploaded by No Comment TV
<http://www.euronews.com/nocomment/> Vladimir Putin announcing he could help the Russian Judo Team if ...

Putin Judo - YouTube



https://www.youtube.com/watch?v=1dXwu2MXR_s
Jun 14, 2006 - Uploaded by timourkh
Russian President Vladimir Putin has a black belt in Judo.

Putin & Co to teach you judo - YouTube



<https://www.youtube.com/watch?v=C7yjCaCQP08>
Oct 7, 2008 - Uploaded by RT



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Francois Hollande's scooter trips to visit mistress spawn ...

www.dailymail.co.uk/news/article-2539600

Video embedded - **Francois Hollande ridiculed** in video game parody of his secret scooter trips to visit mistress Julie Gayet. Online game lampooning French President ...

François hollande sur un scooter ! - YouTube

www.youtube.com/watch?v=1zGXlCAkk1A ▾

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Photographer reveals how he tracked down **François Hollande**





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Bunga Bunga feat. Silvio Berlusconi - YouTube



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iTUNES: <https://goo.gl/9iEm2w> AMAZON: <http://goo.gl/c12pbU>
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Silvio Berlusconi: Bunga Bunga - YouTube



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Sep 30, 2011 - Uploaded by Goldfinger200

In seiner Freizeit ist er Regierungschef. Berlusconi erzählt schmutzige Witze. Viele Italiener fühlen sich ...

Ruby Berlusconi e il BUNGA BUNGA - YouTube



<https://www.youtube.com/watch?v=8AFFjsYpjw8>

Nov 4, 2010 - Uploaded by giovanni cangaceiro

Ruby Berlusconi e il BUNGA BUNGA ... IL VIDEO CHE HA FATTO INFURIARE IL PREMIER ALL ...



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CNN

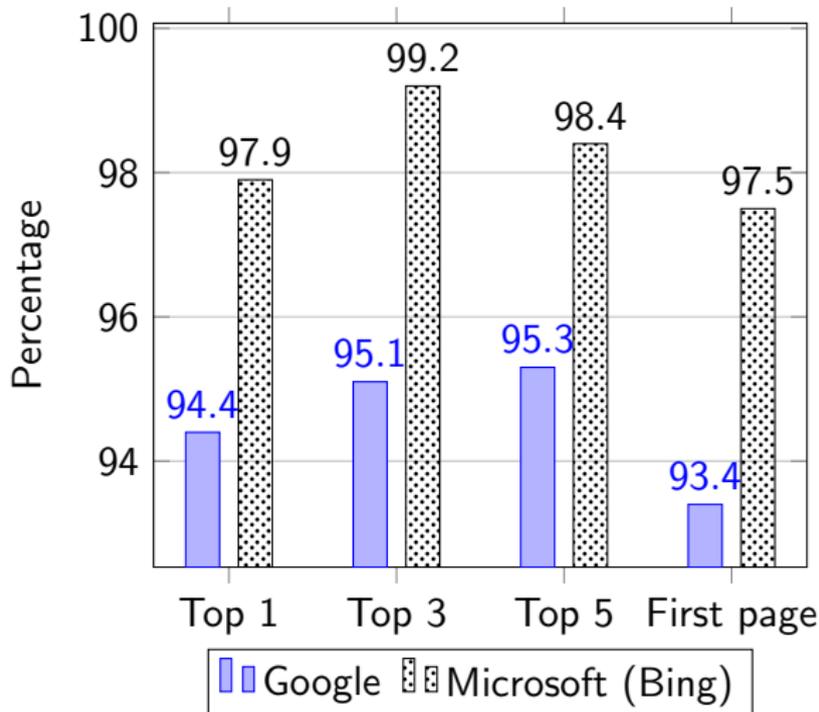
Do search engines return biased results?

Comparison between Google, Bing, and Blekko (Wright, 2012):

- ▶ Microsoft content is 26 times more likely to be displayed on the first page of Bing than on any of the two other search engines
- ▶ Google content appears 17 times more often on the first page of a Google search than on the other search engines

Search engines do favor their own content

Do search engines return biased results?



Percentage of Google or Bing search results with **own content not ranked similarly** by any rival search engine (Wright, 2012).

Search Neutrality (relevance only)

Some say search engines should be considered as a **public utility**.

Idea of **search neutrality**: All content should have the same chance of being displayed if they have equivalent relevance. Content of higher relevance should never be displayed in worst position.

More fair, better for users and for economy, encourages quality, etc.

What is the precise definition of “**relevance**”? Not addressed here ...

Debate: Should neutrality be imposed by law? Pros and cons.

Regulatory intervention: The European Commission, is progressing toward an antitrust settlement deal with Google.

“Google must be even-handed. It must hold all services, including its own, to exactly the same standards, using exactly the same crawling, indexing, ranking, display, and penalty algorithms.”

In general: trade-off in the rankings

From the viewpoint of the SE: Tradeoff between

- ▶ **relevance** (long term profit)

versus

- ▶ **expected revenue** (short term profit)

Better relevance brings more customers in the long term because it builds reputation.

What if the provider wants to **optimize its long-term profit**?

Start with a simple stylized model

“To get elegant results and insight, start with simplified model. If too hard, simplify more.”

- Newton laws in physics
- Erlang queueing formulas
- Black-Scholes in finance
- Etc.

Model of search requests

Request: random vector $Y = (M, R_1, G_1, \dots, R_M, G_M)$ where

M = number of pages that match the request;

$R_i \in [0, 1]$: measure of **relevance** of page i ;

$G_i \in [0, K]$: **expected revenue** (direct or indirect) from page i .

Y has a prob. distribution over $\Omega = \mathbb{N} \times ([0, 1] \times [0, K])^{m_0}$.

Can be discrete or continuous.

$y = (m, r_1, g_1, \dots, r_m, g_m)$ denotes a realization of Y .

$c_{i,j}(y) = \mathbb{P}[\text{click page } i \text{ if in position } j] = \text{click-through rate (CTR)}$.

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Decision (ranking) for any request y : Permutation $\pi = (\pi(1), \dots, \pi(m))$ of the m matching pages. $j = \pi(i) = \text{position of } i$.

Local relevance and **local revenue** for y and π :

$$r(\pi, y) = \sum_{i=1}^m c_{i,\pi(i)}(y) r_i,$$

$$g(\pi, y) = \sum_{i=1}^m c_{i,\pi(i)}(y) g_i.$$

Deterministic stationary ranking policy μ

It assigns a permutation $\pi = \mu(y) \in \Pi_m$ to each $y \in \Omega$.

Long-term **expected relevance** per request (reputation of the provider) and **expected revenue** per request (from the organic links), for given μ :

$$r = r(\mu) = \mathbb{E}[r(\mu(Y), Y)],$$

$$g = g(\mu) = \mathbb{E}[g(\mu(Y), Y)].$$

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$$\begin{aligned} r &= r(\mu) = \mathbb{E}[r(\mu(Y), Y)], \\ g &= g(\mu) = \mathbb{E}[g(\mu(Y), Y)]. \end{aligned}$$

Objective: Maximize long-term utility function $\varphi(r, g)$.

Assumption: φ is **strictly increasing** in both r and g .

Example: expected revenue per unit of time

$$\varphi(r, g) = \lambda(r)(\beta + g), \quad \text{where}$$

$\lambda(r)$ = **arrival rate** of requests, strictly increasing in r ;

β = \mathbb{E} [revenue per request] from **non-organic** links (ads on root page);

g = \mathbb{E} [revenue per request] from **organic** links.

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Q: Is this the most general type of policy?

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Randomized stationary ranking policy $\tilde{\mu}$

$$\tilde{\mu}(y) = \{q(\pi, y) : \pi \in \Pi_m\}$$

is a probability distribution, for each $y = (m, r_1, g_1, \dots, r_m, g_m) \in \Omega$.

Let $z_{i,j}(y) = \mathbb{P}[\pi(i) = j]$ under $\tilde{\mu}$.

Expected relevance

$$r = r(\tilde{\mu}) = \mathbb{E} \left[\sum_{\pi} q(\pi, Y) \sum_{i=1}^M c_{i,\pi(i)}(Y) R_i \right] = \mathbb{E} \left[\sum_{i=1}^M \sum_{j=1}^M z_{i,j}(Y) c_{i,j}(Y) R_i \right]$$

Expected revenue

$$g = g(\tilde{\mu}) = \mathbb{E} \left[\sum_{\pi} q(\pi, Y) \sum_{i=1}^M c_{i,\pi(i)}(Y) G_i \right] = \mathbb{E} \left[\sum_{i=1}^M \sum_{j=1}^M z_{i,j}(Y) c_{i,j}(Y) G_i \right].$$

In terms of (r, g) , we can redefine (simpler)

$\tilde{\mu}(y) = \mathbf{Z}(y) = \{z_{i,j}(y) \geq 0 : 1 \leq i, j \leq m\}$ (doubly stochastic matrix).

Q: Here we have a **stochastic dynamic programming** problem, but the rewards are not additive! Usual DP techniques do not apply.

How can we compute an optimal policy?

Seems very hard in general!

Optimization problem

$$\max_{\tilde{\mu} \in \tilde{\mathcal{U}}} \varphi(r, g)$$

subject to

$$r = \mathbb{E} \left[\sum_{i=1}^M \sum_{j=1}^M z_{i,j}(Y) c_{i,j}(Y) R_i \right]$$

$$g = \mathbb{E} \left[\sum_{i=1}^M \sum_{j=1}^M z_{i,j}(Y) c_{i,j}(Y) G_i \right]$$

$$\tilde{\mu}(y) = \mathbf{Z}(y) = \{z_{i,j}(y) : 1 \leq i, j \leq m\} \quad \text{for all } y \in \Omega.$$

Optimization problem

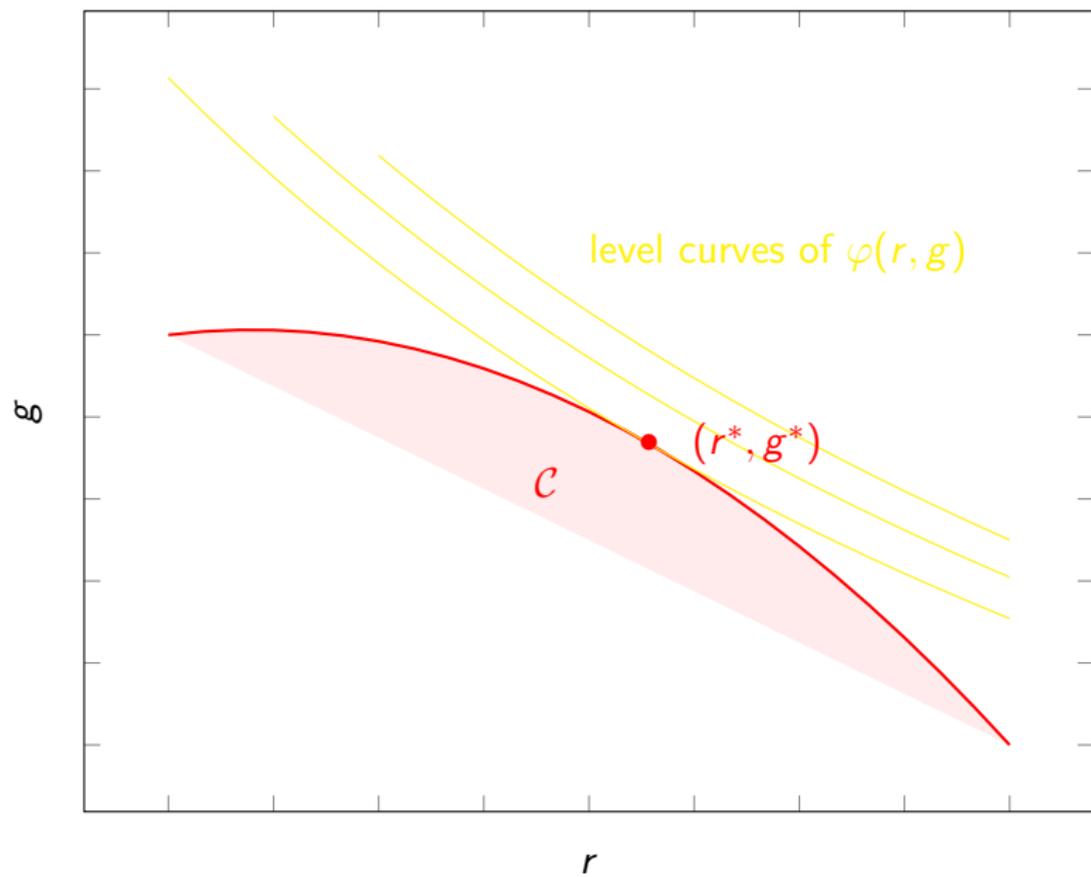
$$\begin{aligned}
 & \max_{\tilde{\mu} \in \tilde{\mathcal{U}}} \quad \varphi(r, g) \\
 & \text{subject to} \\
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 \end{aligned}$$

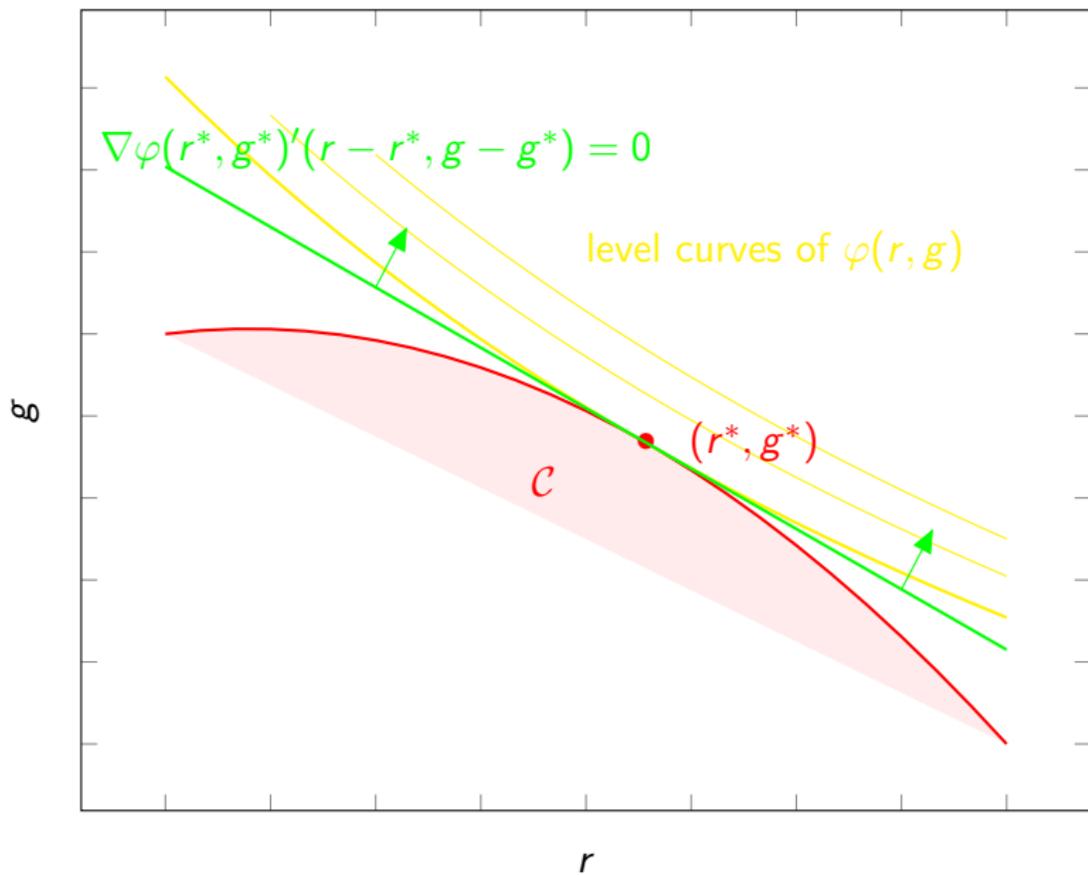
To each $\tilde{\mu}$ corresponds $(r, g) = (r(\tilde{\mu}), g(\tilde{\mu}))$.

Proposition: The set $\mathcal{C} = \{(r(\tilde{\mu}), g(\tilde{\mu})) : \tilde{\mu} \in \tilde{\mathcal{U}}\}$ is convex.

Optimal value: $\varphi^* = \max_{(r,g) \in \mathcal{C}} \varphi(r, g) = \varphi(r^*, g^*)$ (optimal pair).

Idea: find (r^*, g^*) and recover an optimal policy from it.





Optimization

$$\nabla\varphi(r^*, g^*)'(r - r^*, g - g^*) = \varphi_r(r^*, g^*)(r - r^*) + \varphi_g(r^*, g^*)(g - g^*) = 0.$$

Let $\rho^* = \varphi_g(r^*, g^*)/\varphi_r(r^*, g^*) =$ slope of gradient.

Optimal value = $\max_{(r,g) \in \mathcal{C}} \varphi(r, g) = \max_{(r,g) \in \mathcal{C}} (r - r^* + \rho^*(g - g^*)).$

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Optimal "solution" satisfies $(r^*, g^*) = \arg \max_{(r,g) \in \mathcal{C}} (r + \rho^*g)$.

The optimal (r^*, g^*) is unique if the contour lines of φ are strictly convex.
True for example if $\varphi(r, g) = r^\alpha(\beta + g)$ where $\alpha > 0$.

The arg max is **unique** if and only if green line

$$\varphi_r(r^*, g^*)(r - r^*) + \varphi_g(r^*, g^*)(g - g^*) = 0 \text{ touches } \mathcal{C} \text{ at a single point.}$$

One more assumption

Standard **assumption**: click-through rate has **separable** form:

$$c_{i,j}(y) = \theta_j \psi(r_i),$$

where $1 \geq \theta_1 \geq \theta_2 \geq \dots \geq \theta_{m_0} > 0$ (ranking effect)
and $\psi : [0, 1] \rightarrow [0, 1]$ increasing.

Let $\tilde{R}_i := \psi(R_i)R_i$, $\tilde{G}_i := \psi(R_i)G_i$, and similarly for \tilde{r}_i and \tilde{g}_i . Then

$$r = \mathbb{E} \left[\sum_{i=1}^M \sum_{j=1}^M z_{i,j}(Y) \theta_j \tilde{R}_i \right]$$

and similarly for g .

Optimality conditions, discrete case

Definition. A linear ordering policy with ratio ρ (LO- ρ policy) is a (randomized) policy that ranks the pages by decreasing order of their value of $\tilde{r}_i + \rho\tilde{g}_i$ with probability 1, for some $\rho > 0$, except perhaps when $\theta_{j'} = \theta_j$ where the order does not matter.

Theorem. Suppose Y has a discrete distribution, with $p(y) = \mathbb{P}[Y = y]$. Then any optimal randomized policy must be an LO- ρ policy.

Idea of proof: by an interchange argument. If for some y with $p(y) > 0$, page i at position j has lower score $\tilde{r}_i + \rho\tilde{g}_i$ than the page at position $j' > j$ with probability $\delta > 0$, we can gain by exchanging those pages, so this is cannot be optimal.

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Nice!

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Right?

Beware of equalities!

What if two or more pages have the same value of $\tilde{R}_i + \rho^* \tilde{G}_i$?
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The answer is **NO**.

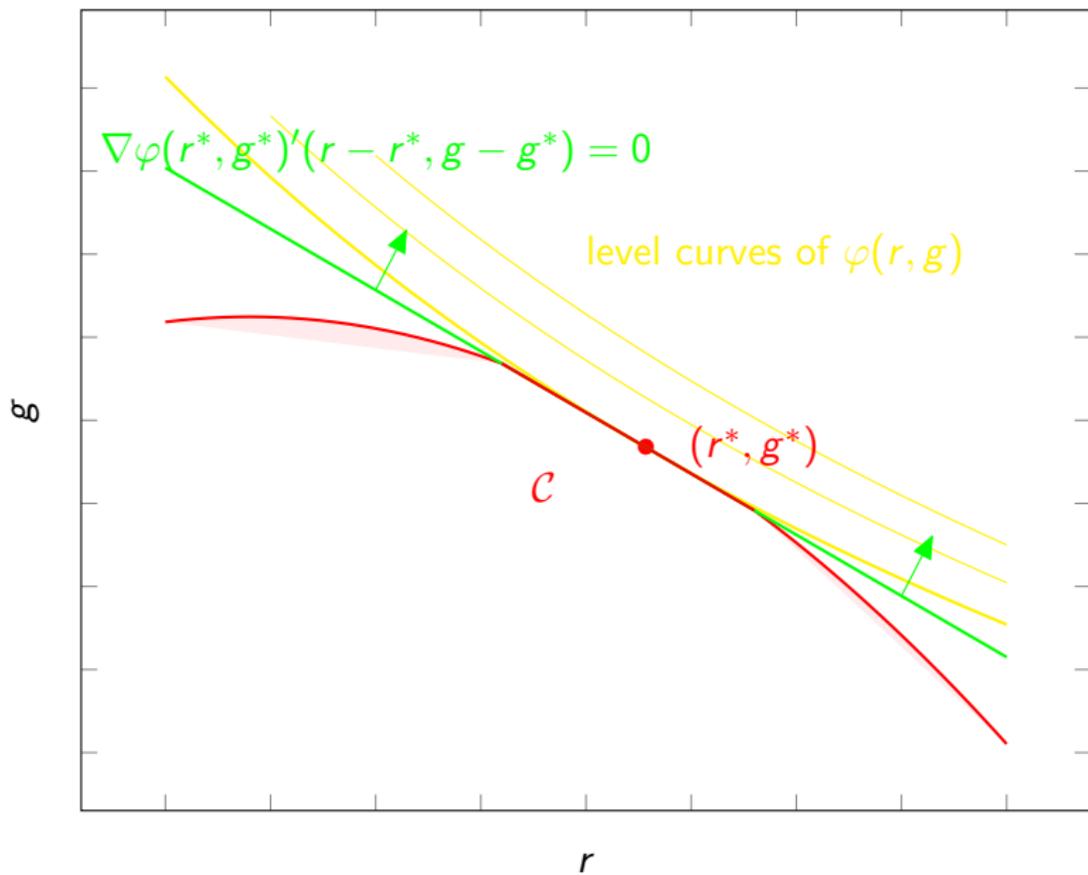
Beware of equalities!

What if two or more pages have the same value of $\tilde{R}_i + \rho^* \tilde{G}_i$?

Can we rank them arbitrarily?

The answer is **NO**.

Specifying ρ^* is not enough to uniquely characterize an optimal policy when equality can occur with positive probability.



Counter-example.

Single request $Y = y = (m, r_1, g_1, r_2, g_2) = (2, 1, 0, 1/5, 2)$.

$\psi(r_i) = 1$, $(\theta_1, \theta_2) = (1, 1/2)$, $\varphi(r, g) = r(1 + g)$.

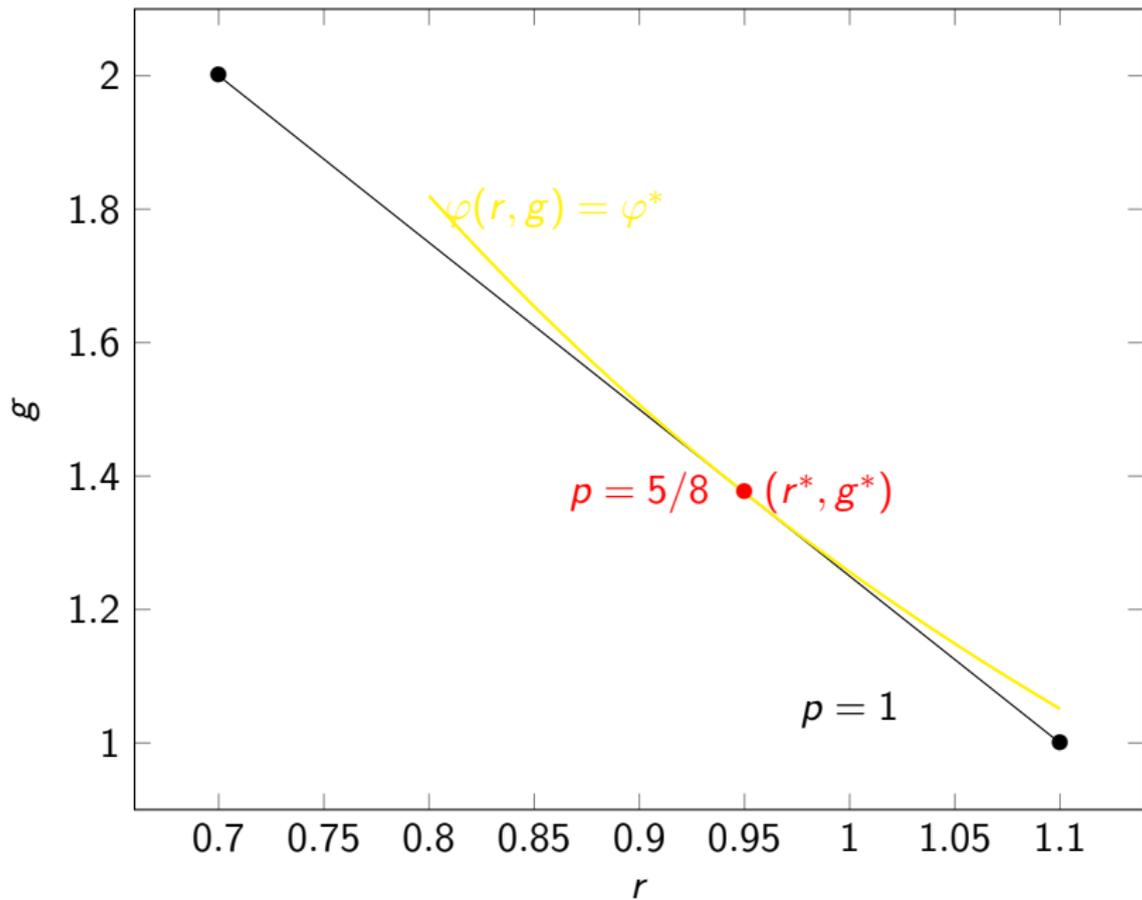
For each request, $\mathbb{P}[\text{ranking } (1, 2)] = p = 1 - \mathbb{P}[\text{ranking } (2, 1)]$.

One finds that $\varphi(r, g) = (7 + 4p)(3 - p)/10$, maximized at $p^* = 5/8$.

This gives $r^* = 19/20$, $g^* = 11/8$, $\varphi(r^*, g^*) = 361/160$.

$p = 0$ gives $\varphi(r, g) = 336/160$ and $p = 1$ gives $\varphi(r, g) = \varphi^* = 352/160$.

No optimal deterministic policy here!



Continuous distribution for Y

Definition. A randomized policy $\tilde{\mu}$ is called an **LO- ρ policy** if for almost all Y , $\tilde{\mu}$ sorts the pages by decreasing order of $\tilde{R}_i + \rho\tilde{G}_i$, except perhaps at positions j and j' where $\theta_j = \theta_{j'}$, at which the order can be arbitrary.

Theorem (necessary conditions). Any optimal policy must be an LO- ρ policy with $\rho = \rho^*$.

Continuous distribution for Y

Assumption A. For any $\rho \geq 0$ and $j > i > 0$,

$$\mathbb{P}[M \geq j \text{ and } \tilde{R}_i + \rho \tilde{G}_i = \tilde{R}_j + \rho \tilde{G}_j] = 0.$$

Theorem (sufficient condition). Under Assumption A, for any $\rho \geq 0$, a **deterministic** LO- ρ policy sorts the pages for Y uniquely with probability 1. For $\rho = \rho^*$, this policy is optimal.

Idea: With probability 1, there is no equality.

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Idea: With probability 1, there is no equality.

In this case, it suffices to find ρ^* , which is a root of

$$\rho = \tilde{h}(\rho) := h(r, g) := \varphi_g(r, g) / \varphi_r(r, g).$$

Can be computed by a root-finding technique.

Proposition. (i) If $h(r, g)$ is bounded over $[0, 1] \times [0, K]$, then the fixed-point equation $\tilde{h}(\rho) = \rho$ has at least one solution in $[0, \infty)$.
 (ii) If the derivative $\tilde{h}'(\rho) < 1$ for all $\rho > 0$, then the solution is unique.

Proposition.

Suppose $\varphi(r, g) = \lambda(r)(\beta + g)$.

- (i) If $\lambda(r)/\lambda'(r)$ is bounded for $r \in [0, 1]$ and $g(\rho(0)) > 0$, then the fixed point equation has at least one solution in $[0, \infty)$.
- (ii) If $\lambda(r)/\lambda'(r)$ is also non-decreasing in r , then the solution is unique.

Often, $\rho \mapsto \tilde{h}(\rho)$ is a contraction mapping. It is then rather simple and efficient to compute a fixed point iteratively.

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In this continuous case, computing an optimal deterministic policy is relatively easy. It suffices to find the root ρ^* and use the LO- ρ^* policy, which combines optimally relevance and profit.

What to do for the discrete case?

Very often, only a randomized policy can be optimal. But such a policy is very hard to compute and use in general! Not good!

Much simpler and better solution:

In case of equality, add a small noise to R_i for each i involved in an equality.

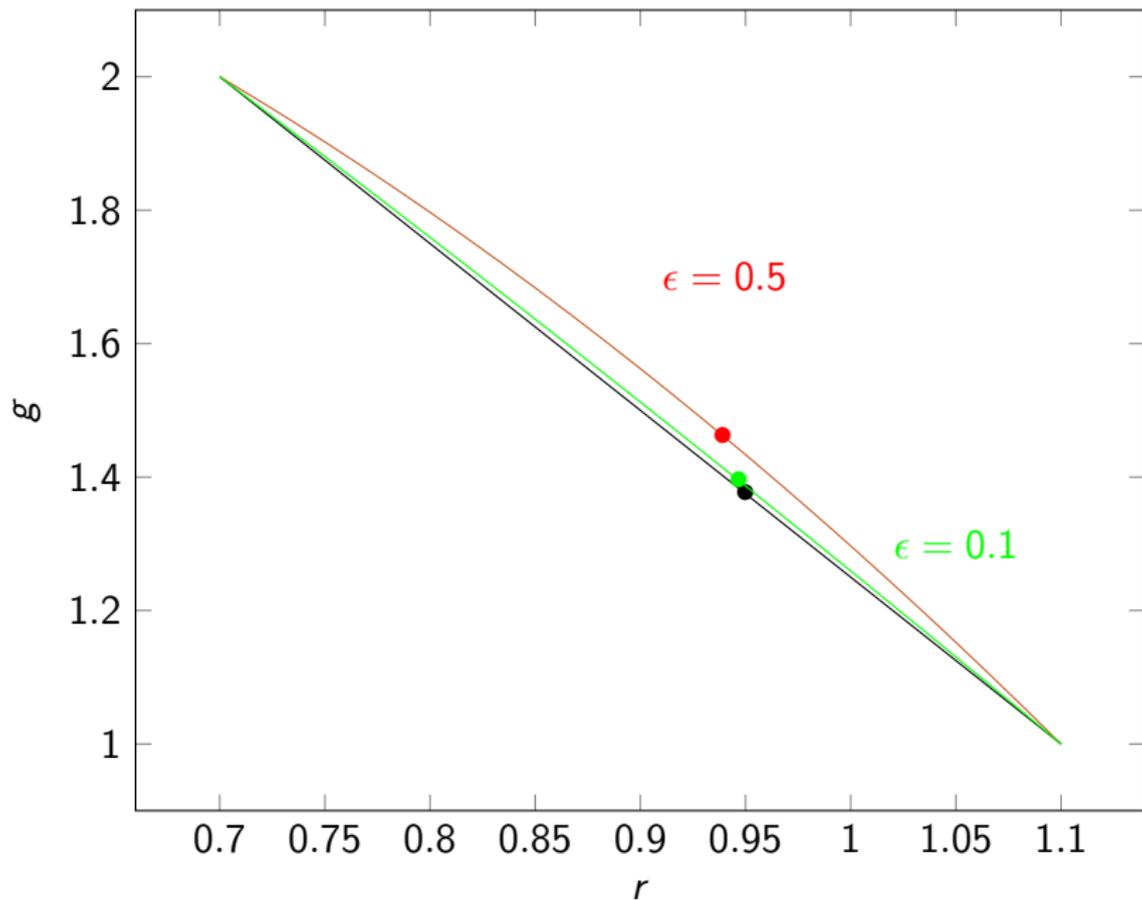
These noises can be taken uniform over $(-\epsilon, \epsilon)$ for some tiny ϵ .

Then the probability of an equality becomes 0.

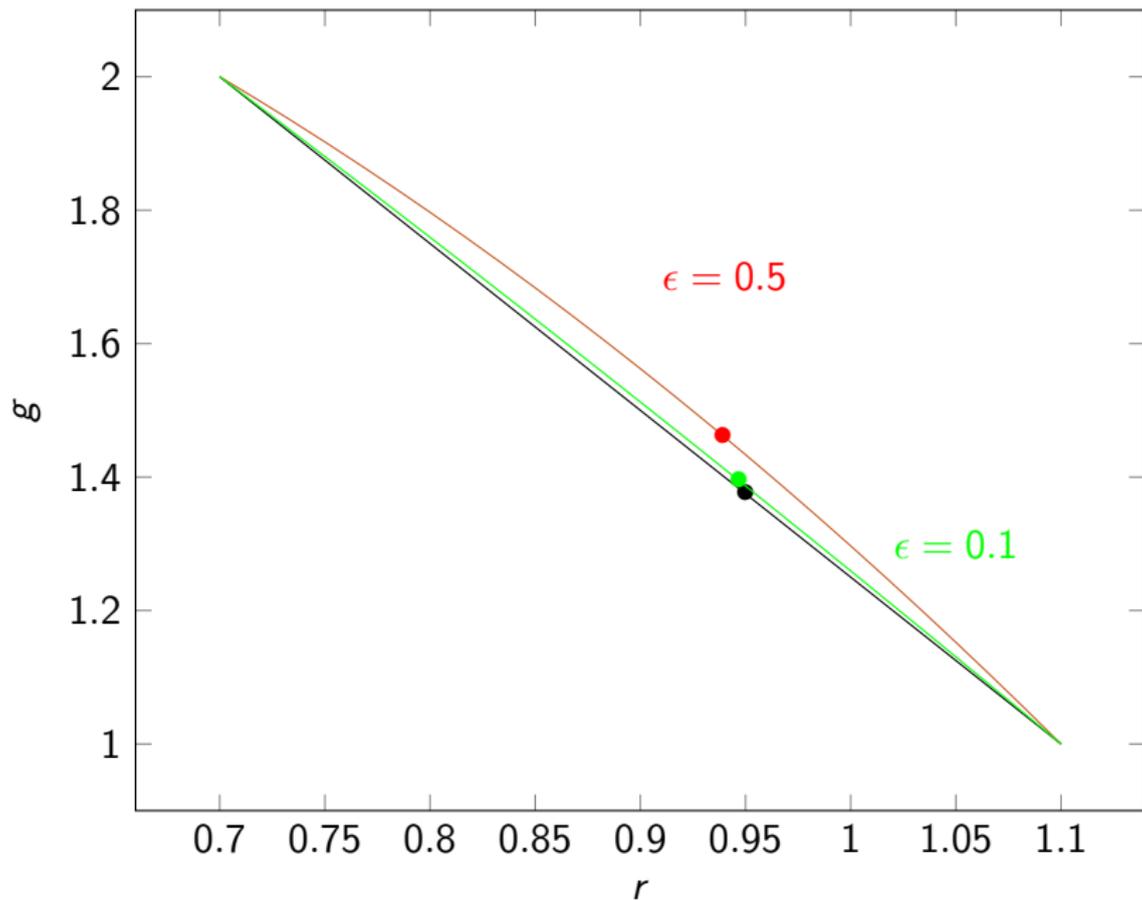
For very small ϵ (e.g., $10^{-10}R_i$), the impact is negligible.

If suffices to compute ρ^* with this “perturbed distribution.”

Application to previous example



Application to previous example



More details

P. L'Ecuyer, P. Maille, N. Stier-Moses, and B. Tuffin. Revenue-Maximizing Rankings for Online Platforms with Quality-Sensitive Consumers.

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On my web page.

Also at <https://hal.inria.fr/hal-00953790>.

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