Information Revelation and Consumer Privacy

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FTC Microeconomics Conference

November 13th, 2015

Introduction

Wide collection and di¤usion of personal data in online markets.

- Sources: recorded purchases, browser cookies, social media.
- Uses: customized search results, web content, targeted advertising, promotional o¤ers.

Consumers have partial control over available information.

This paper: equilibrium analysis with rational consumer.

- Consumer has no intrinsic value of privacy.
- Understands information collection (pro…le building) mechanism and its payo¤ consequences.

BIG DATA AND DIFFERENTIAL PRICING

February 2015

Research Questions

Model: Approach

Noisy ratchet-e¤ect model with details from online markets.

Consumers' preferences are private information.

Each consumer interacts with heterogeneous …rms: sellers and websites (non-merchant content providers).

Each interaction generates information of endogenous precision.

Firms use information (from either source) in future interactions.

- Aligned interests: matching content to tastes.
- Con‡ict: matching products and prices to willingness to pay.

Model: Payo¤s

Consumer has type (q_q, q_z) = (taste for product, taste for news).

Correlated "vertical" and "horizontal" and components.

Today: perfectly correlated $q_q = q_z = q$.

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Linear-quadratic-‡ow utility function

$$U(q, q, z; p, w) = (q \quad p)\, q \quad q^2/2 \quad (q \quad z)^2 \quad (w \quad z)^2.$$

Sellers maximize pro…ts

$$P(p, q) = p \quad q.$$

Websites want to match content to consumer's type

$$L(q, w) = \quad (w \quad q)^2.$$

Model: Information

Prior distribution of consumer's type

$$q \quad N(q_0, 1/t_0).$$

Consumer's actions at $t = 1$ recorded with noise.

1. Browsing history
$$s_z \quad N(z, 1/t_z).$$
2. Purchase history
$$s_q \quad N(q, 1/t_q).$$

Firms at $t = 2$ observe (part of) the consumer's record.

Information set of firm j $2 \{W, S\}$

$$I_j \quad \{s_q, s_z\}.$$

Model: Discussion

What is the source of con‡ict between consumers and …rms?

Consumer's Problem

Given …rms' beliefs m_j , $E[q \mid I_j]$, continuation payo¤:

$$V_2(q, m_S, m_W) = \frac{1}{2}\left(q - \frac{m_S}{2}\right)^2 - \frac{1}{2}(q - m_W)^2.$$

- Wants seller to under-estimate q and webrTJ ET q 9eo under-elea

2m@(and webinfoTJ Erm334(pa)283m

[q, m_S) hurtscontinuatv4 11.3673 Tf 9.924 145.2461Td [(])]TJ/FJ/F66 10.9091 Tf 4.68 0.115 Td [(q)]T

Private Signals

Firms' Beliefs

Firms' Beliefs

To form beliefs, …rms conjecture linear strategies

$$q_1 = a_q\ q + b_q(p, w),$$
$$z_1 = a_z\ q + b_z(p, w).$$

Linearity + normality) consumer in‡uences $E[m_S], E[m_W]$ only.

Consumers' …rst-period best replies (q_1, z_1) satisfy

$$q = q\ p\ \frac{1}{2}\ q\ \frac{E[m_S \mid q]}{2}\ \frac{\P E[m_S \mid q]}{\P q},$$
$$z = \frac{q + w}{2} + (q\ E[m_W \mid z])\ \frac{\P E[m_W \mid z]}{\P z}.$$

- Linear conjectures, linear replies, match coe¢ cients.

Proposition (Equilibrium with Private Signals)

There exists a unique equilibrium in linear strategies:

$$\begin{aligned} q_1(q, p) &= a_q(t_q)\, q + d_q(t_q)\, q_0 - p, \\ z_1(q, w) &= a_z(t_z)\, q + d_z(t_z)\, q_0 + w/2. \end{aligned}$$

1. Signal precisions $a_q^2 t_q$ and $a_z^2 t_z$ are increasing in t_q and t_z.
2. The browsing weight $a_z - 1/2$ is inverse-U shaped in t_z.
3. The purchase weight $a_q - 1$ is strictly decreasing in t_q.
4. First-period price $p_1 = q_0 - a_q + d_q / 2$, decreasing in t_q.

Welfare with Private Signals

Consider ex ante welfare of consumers and sellers.

Decompose surplus into mean (μ_0) and variance (t_q) effects.

Welfare with Private Signals

Consider ex ante welfare of consumers and sellers.

Decompose surplus into mean (q_0) and variance (t_q) effects.

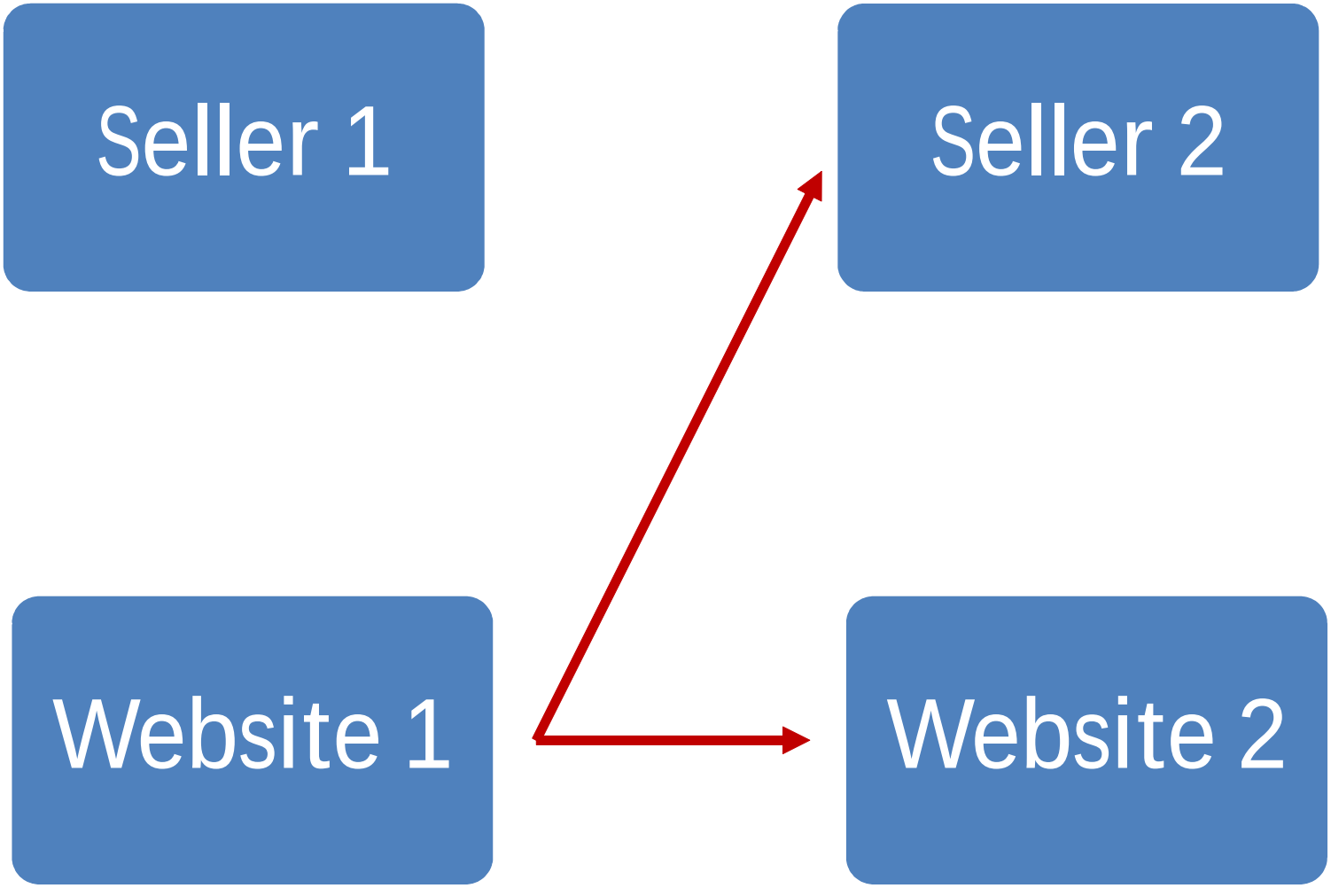
Proposition (Welfare with Private Signals)

1. Consumer surplus is increasing in t_2.
2. Consumer surplus is inverse-U shaped in t_q (strictly decreasing if $q_0^2 t_q$ 6).
3. Producer surplus is inverse-U shaped in t_q (strictly decreasing if $q_0^2 t_q$ 2).
4. Total surplus is strictly decreasing in t_q.

Parameters:$(q_0, t_q, t_z) = (5, 1, 0)$

Public Signals

Public Signals



Public vs. Private Browsing Signal

Consumer Surplus: Comparison

Proposition (E¤ect of Leakages)

1. For all t_z, ex ante consumer surplus is higher when browsing signals are private.
2. For all t_q, period-1 prices are higher when purchase signals are public.
3. For su¢ ciently large t_q, consumer surplus is higher when purchase histories are public.

Payo¤ Comparison: Purchase Signal

Public vs. Private Purchases

Public purchase signals introduce signaling value through q_0.

Trade-o¤:

- better match with period-2 website,
- vs. higher period-1 price.

With high precision t_q, a small change in q_1 su¢ces to signal
) public purchase signals are bene…cial.

A closer look: public purchases increase consumer surplus restricted to her interaction with sellers.

Implications for Consumers

Implications for Consumers

Two kinds of information, very di¤erent e¤ects.

"Compensation" for information revealed within a transaction.

Consumer cannot be compensated when "just browsing."

Bene…ts of cross-tracking of purchases.

Downsides to cross-tracking of "browsing" behavior.

> "A poorly thought out legislative solution would likely result in a very rigid framework that assigned individuals additional rights with respect to information about themselves, but did not allow for ways to sell such property rights in exchange for other considerations." (Varian, 1996)

Implications for Firms

Fix signal technologies $t_q > 0$, $t_z > 0$.

Websites access purchase histories:

informational content of

Implications for Firms

Fix signal technologies $\tau_q > 0$, $\tau_z > 0$.

Websites access purchase histories:

- informational content of browsing signal $\alpha_z^2 \tau_z$ decreases.

Sellers access browsing histories:

- informational content of purchase signal $\alpha_q^2 \tau_q$ increases;
- …rst-period price increases.

Strong incentives for sellers to purchase browsing signals.

Place in the Literature

"The Economics of Privacy" by Acquisti, Taylor, and Wagman (forthcoming JEL).

Behavior-based price discrimination: Fudenberg and Villas-Boas (2006, 2012).

Tracking and selling purchase histories: Taylor (2004), Acquisti and Varian (2005), Hermalin and Katz (2006).

Selling consumer-level information: Bergemann and Bonatti (2015), Bergemann, Bonatti and Smolin (2015).

Richer Information Structures

Numerical results show that

1. There exists $\bar{t}_q$

Steady-State Model

Value of signaling is e¤ectively exogenous.

Pure price discrimination. In each period, meet a di¤erent seller.

The consumer's type q_t follows

$$dq_t = \quad k(q_t \quad q_0)dt + s_q dZ_t^q.$$

The purchases signal is given by

$$dY_t = aq_t\,dt + s_Y\,dZ_t^Y.$$

Steady-State of Learning

The market's posterior mean is m_t follows

$$dm_t = k(m_t - q_0)dt + \frac{a_t g_t}{s_Y^2}(dY_t - am_t dt),$$

The variance g_t is deterministic, with

$$\dot{g}_t = -2kg_t + s_q^2 - \frac{ag_t}{s_Y}^2.$$

Proposition (Public Browsing Signal)

1. The weight a_z on the consumer's type a is inverse-U shaped in t_z and below its myopic level ($a = 1/2$) for large enough t_z.
2. The precision of the …rms' beliefs is increasing in t_z.
3. Consumer surplus is inverse-U shaped in t_z.

Continuation Game (Myopic Benchmark)

Consumers' best replies:

$$\begin{aligned} q_2 &= q - p, \\ z_2 &= (q + w)/2. \end{aligned}$$

Period-2 firms' beliefs:

$$\begin{aligned} m_S &, \quad E[q \mid I_S] \\ m_W &, \quad E[q \mid I_W] \end{aligned}$$

Seller and website choose

$$\begin{aligned} p_2 &= m_S/2, \\ w_2 &= m_W. \end{aligned}$$

Equilibrium with Private Signals

Consumers' …rst-period best replies (q_1, z_1) satisfy

$$q = p - \frac{1}{2} q - \frac{E[m_S \mid q]}{2} - \frac{\partial E[m_S \mid q]}{\partial q},$$

$$z = \frac{q + w}{2} + (q - E[m_W \mid z]) \frac{\partial E[m_W \mid z]}{\partial z}.$$

Equilibrium:

- Linear conjectures, linear replies, match coe¢ cients.
- Amount of information conveyed by the signals is endogenous.