

# Net Neutrality and Investment

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# How Does Net Neutrality Affect Investment Incentives?

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- Among issues in net neutrality debate is impact of price discrimination on investment incentives.
  - For application/content providers (e.g., Google)
  - For platforms (e.g., ATT in US)
- More generally, how does ability of seller to price discriminate affect buyers’ (e.g., application/content providers’) and seller’s incentives to invest?

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# Papers under Discussion

- Impact on buyers' incentives: "Information and the Hold-Up Problem" by Hermalin & Katz
- Impact on ISP's (seller's) incentives: ongoing Economides & Hermalin project

# Buyers Often Make Investments Prior to Purchase

## Examples

- Internet content/application provider invests prior to purchasing Internet access.
- Coal mine reliant on the local railroad.
- Firm invests in innovation that relies on licensing technology from other firm.
- Retailer/franchisee making complementary investments in order to distribute a manufacturer's product.

# A Hold-up Problem Exists

Much studied problem in economics

- When contracting feasible in **advance** of investment, clever contracts sometimes exist to solve problem (e.g., Demski & Sappington, *RAND*, 1991).
- Many situations exist, however, where advanced contracting not feasible (e.g., need to buy seller's good might not be obvious *ex ante*).
- Moreover, when contracts *not* robust to renegotiation, optimal *ex ante* contract can be no contract (see Edlin & Hermalin, *JLEO*, 2000).
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# Basic Model Timing

- ① Buyer sinks investment that has value only if buy good from seller.
- ② Buyer learns value of trade.
- ③ Seller makes buyer take-it-or-leave-it (TIOLI) offer. When making offer, seller may possess information about buyer's investment or value of trade.
- ④ Buyer chooses to buy or not from seller.
- ⑤ Payoffs realized.

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# Role of Information

- If seller learns buyer's value, then
  - Complete holdup
  - Buyer has no investment incentives
  - Joint profits minimized
- If seller has no information, buyer has incentives to invest. Joint profits greater.
- Conclusion: buyer and seller jointly prefer complete seller ignorance to symmetric information.
- Suggests: improving seller's information lowers the buyer's profits and investment incentives.

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- But what if put more structure on the problem?
- Suppose
  - investment improves the distribution of the buyer's returns in the sense of first-order stochastic dominance; and
  - a higher value of the seller's signal leads to an improvement in the conditional distribution of the buyer's returns in the sense of first-order stochastic dominance.
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  - seller's price is increasing in the signal's value.
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# False Conclusions

The “conclusions” on the previous slide are false!

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# Assumptions

- As shorthand, refer to buyer's product-market quasi-rents as the buyer's revenues. Denote these by  $r \in [0, \bar{r}]$ ,  $\bar{r}$  finite.
- If buyer does not buy from seller, then  $r = 0$  regardless of buyer's investment.
- If buyer purchases from seller, then buyer's revenues have the conditional distribution  $F(r, s|I)$ , where
  - $s$  is a signal whose properties will be discussed below.
  - $I$  is amount invested by buyer.
- $f(r, s|I)$  denotes the corresponding density function.

# Assumptions (continued)

- Buyer's profit if buys:  $r - p - I$ , where  $p$  price paid
- Buyer's profit if doesn't buy:  $-I$ .
- Seller's profit if buyer buys,  $p$  (cost to seller set at zero for convenience).

# Notation

- $F_r(r|I)$  marginal distribution of revenue,  $r$ , given investment,  $I$ .  
 $f_r(r|I)$  corresponding density function.
- $h(r|I) = \frac{f_r(r|I)}{1-F_r(r|I)}$  corresponding hazard rate.
- Note  $1 - F_r(p|I) \equiv D(p|I)$  is expected demand faced by seller at price  $p$  (normalizing measure of buyers to 1).

# Three Possible Consequences of Buyer Investment

- ① *Productive Investment*: An increase in  $I$  raises the expected value of  $r$ .
- ② *FOSD Improvement*: An increase in  $I$  improves the distribution of  $r$  in the sense of first-order stochastic dominance (FOSD).
- ③ *Moral Hazard*: For any  $I > 0$  and  $r < \bar{r}$ , the hazard rate  $h(r|I)$  is non-decreasing in  $r$  and decreasing in  $I$ .

Note ③  $\Rightarrow$  ②  $\Rightarrow$  ①.

- Assume ① always holds.
- Note ② can be too strong: Suppose low investment yields a modest return with near certainty, but high (breakthrough) investment have significant probabilities of very low or very high returns.

# Interpretations of Signal

- 1 *Uninformed-seller case*:  $s$ , seller's signal, is completely uninformative about  $I$  and  $r$ .
- 2 *Observable-investment case*:  $s = I$ .
- 3 *Noisy-signal-of-returns case*:  $s$  is a noisy, but informative signal of  $r$ .

Note: If  $s$  is noisy signal about  $I$  only and no shifting support, then  $s$  useless to seller — price as if seller totally uninformed.

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# Pure-strategy Equilibria

- **Lemma:** *If the seller's signal is perfectly uninformative, any equilibrium in which the buyer invests a positive amount is a pure-strategy equilibrium.*
- Denote seller's unique best response  $p^*(I)$ .
- Denote buyer's unique best response as  $I^*(p)$ .

# Monotone Hazard Condition $\Rightarrow p^*(I)$ increasing in $I$

- Elasticity,  $\epsilon$ , given by

$$\epsilon \equiv -\frac{d \log (D(p|I))}{d \log p} = \frac{p f_r(p|I)}{1 - F_r(p|I)} = p h(p|I).$$

- MHC  $\Rightarrow \epsilon$  rises with price & falls with investment.
- Lerner markup rule requires  $\epsilon \equiv 1$  (recall  $MC = 0$ ); to maintain that identity, an increase in  $I$  must be offset by an increase in  $p$ .
- Proposition:** *If the Monotone Hazard Condition is satisfied, then the seller's profit-maximizing price is increasing in the buyer's investment level.*

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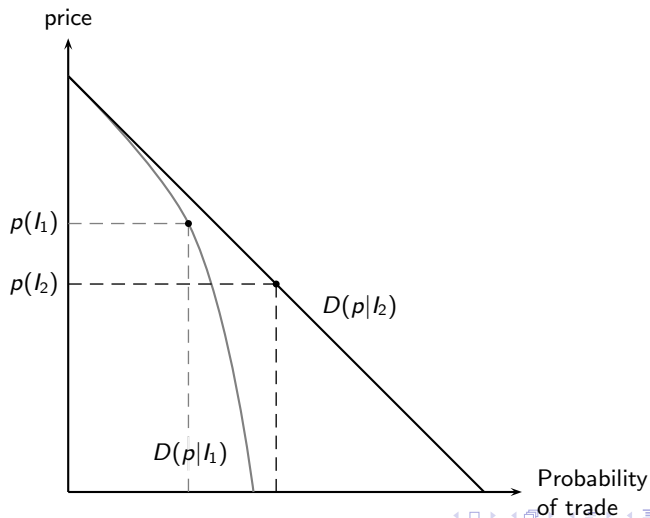
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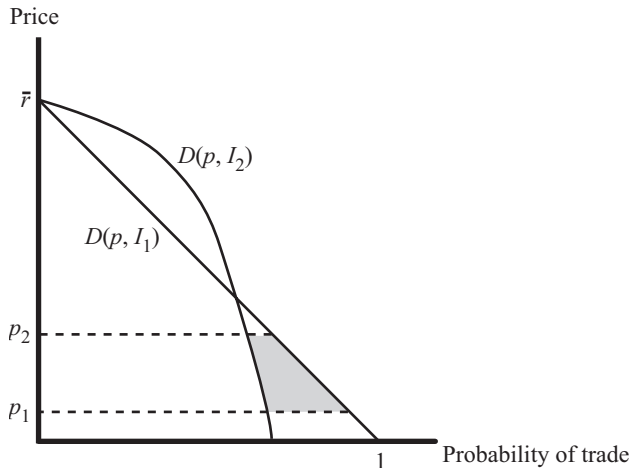
# Why FOSD is not sufficient

Seller's best response is a higher price for low investment ( $l_1$ ) than for high investment ( $l_2$ )



# Effect of Price on Buyer's Investment Incentives

When the FOSD Improvement Condition is not satisfied, a price increase can raise the buyer's investment incentives



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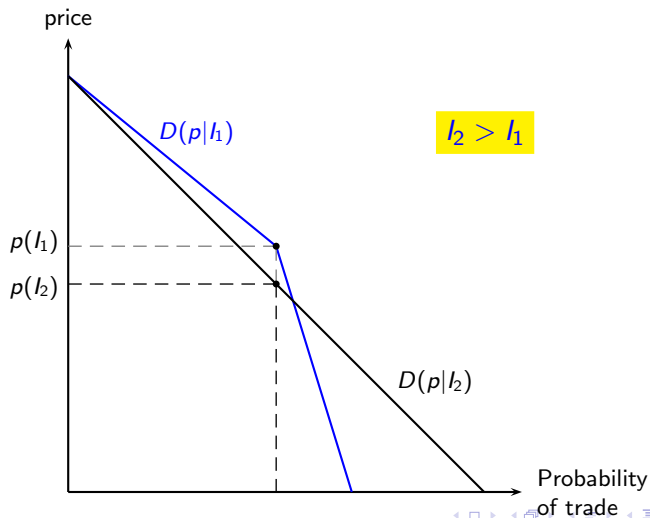
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- A revealed preference argument shows investment level is non-increasing. Concavity of the buyer's optimization program rules out a constant investment level.

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# Effect of Investment on Seller's Expected Profits

Absent FOSD, seller's profits can be greater given low investment than high



# Effect of Investment on Seller's Expected Profits

FOSD implies seller's profit increasing in investment

- **Lemma 4:** *If the FOSD Improvement Condition is satisfied, then the seller's profit is increasing in  $I$  for any  $p \in (0, \bar{r})$ .*
- Proof follows because seller's profit is  $p(1 - F_r(p|I))$  and FOSD  $\Rightarrow F_r(p|I)$  is decreasing in  $I$ .

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# Observable Investment and No Commitment

- The seller can observe the buyer's investment before setting its price.
- Subgame perfection requires that  $p = p^*(I)$ .



# Effect of Observability on Buyer's Investment

- Proposition 5:** *If the Monotone Hazard Condition is satisfied, then the buyer's equilibrium investment level is lower when the seller can observe investment than when the seller's signal is perfectly uninformative, unless both investment levels are zero.* [◀ Back](#)
- Proof:** Let an “o” or “u” superscript denote the equilibrium value of a variable when the seller can base price on  $I$  or not, respectively. By revealed preference,

$$\pi^B(p^*(I^o), I^o) - I^o \geq \pi^B(p^*(I^u), I^u) - I^u \geq \pi^B(p^*(I^u), I^o) - I^o. \quad (1)$$

Suppose  $I^o > I^u$ . Then, because price increases in investment,  $p^*(I^o) > p^*(I^u)$ . But then

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Proof Concluded

To establish  $I^o \neq I^u$  when  $I^u > 0$ , observe that such an  $I^u$  would satisfy the first-order condition

$$\int_{p^*(I^u)}^{\bar{r}} \frac{-\partial F_r(r|I^u)}{\partial I} dr - 1 = 0. \quad (2)$$

In contrast,  $I^o$  satisfies the first-order condition

$$\int_{p^*(I^o)}^{\bar{r}} \frac{-\partial F_r(r|I^o)}{\partial I} dr - p^{*'}(I^o) \left( 1 - F_r(p^*(I^o)|I^o) \right) - 1 = 0. \quad (3)$$

If  $I^o = I^u$ , then  $p^*(I^o) = p^*(I^u)$ . Making those substitutions into (3) and using (2) implies  $p^{*'}(I^o) = 0$ , which contradicts the result that price increases in investment. Hence  $I^o < I^u$ .

# Effect of Observability on Welfare

- One might expect that if observability lowers investment, than observability lowers welfare *vis-à-vis* no observability.
- This is, however, not true.
- Paper constructs example in which observability causes investment to fall, but welfare to increase.
- Reason: Remember there is a second effect — because lower investment causes the seller to lower its price, lower investment can increase the probability of trade.
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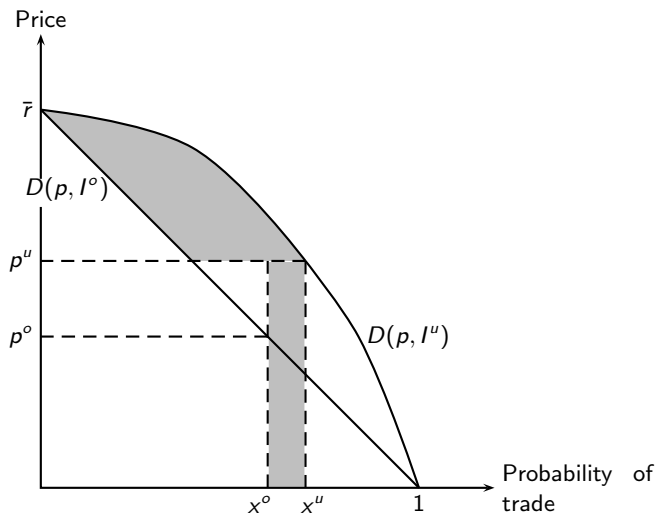


# Conditions for Observability to Reduce Welfare

## Proposition

Suppose that the Monotone Hazard Condition is satisfied. If the equilibrium probability of trade is lower when the seller can observe the buyer's investment than when its signal is perfectly uninformative, then the improvement in the seller's information lowers equilibrium welfare.

# Illustration of Result



# Proof of Result

The change in *total* surplus gross of investment costs exceeds the two shaded regions in the figure. The area of these regions are

$$\pi^B(p^u, I^u) - \pi^B(p^u, I^o) + p^u(x^u - x^o) \quad (4)$$

The result follows if (4) exceeds the incremental cost of investment,  $I^u - I^o$ . That, in turn, follows if

$$(\pi^B(p^u, I^u) - I^u) - (\pi^B(p^u, I^o) - I^o) + (x^u - x^o)p^u > 0.$$

By revealed preference, the difference in the first two terms is positive. And the third term is positive by hypothesis. Therefore, total surplus must be higher when the seller cannot observe the buyer's investment than when it can.

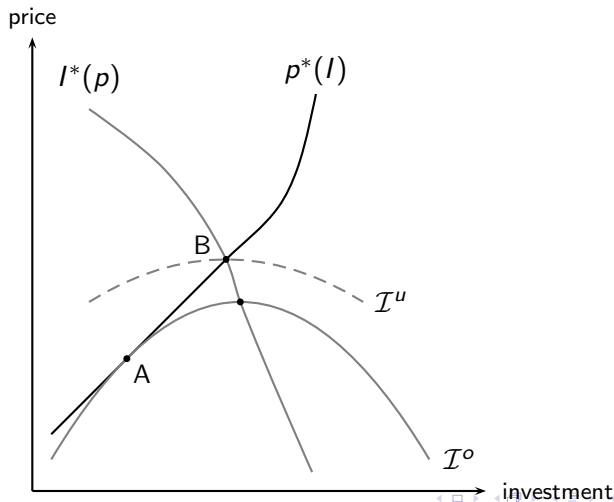
# Effect of Observability on Buyer's Expected Profits

- **Proposition:** *The buyer's equilibrium expected profits are weakly greater when the seller can observe the buyer's investment than when the seller's signal is perfectly uninformative.*
- **Proof:** By revealed preference,

$$\pi^B(p^*(I^o), I^o) - I^o \geq \pi^B(p^*(I^u), I^u) - I^u = \pi^B(p^u, I^u) - I^u.$$

- Note the generality of this result (i.e., does not rest on distributional assumptions).

# Intuition: Observability Makes Buyer Stackelberg Leader of Game



# Effect of Observability on Seller's Expected Profits

- **Proposition:** *If the Monotone Hazard Condition is satisfied, then the seller's equilibrium expected profits are lower when the seller can observe the buyer's investment than when the seller's signal is perfectly uninformative.*
- **Proof:** By Proposition 5,  $I^u > I^o$ .
- Monotone hazard  $\Rightarrow$  FOSD, so result follows from Lemma 4.

# Noisy-Signal-of>Returns Case

- Now signal,  $s$  is an arbitrary signal that is informative, but not fully revealing of what the buyer's return,  $r$ , will be.
- **Extended Monotone Hazard Condition:** For any  $I > 0$ , the hazard rate associated with the distribution of the buyer's returns conditional on its investment and the signal is non-decreasing in return and decreasing in both the signal and investment.
- Even if with this structure hard to get definitive results.

# Results for the Noisy-Signal-of>Returns Case

## A Proposition

Suppose that an increase in investment leads to an improvement in the distribution of  $s$  in the sense of first-order stochastic dominance and that the Extended Monotone Hazard Condition is satisfied. Then:

- 1 the seller's profit-maximizing price increases with both the signal and the anticipated value of investment;
- 2 an increase in investment by the buyer raises the seller's profits;
- 3 given the equilibrium price schedule chosen by the seller, the buyer's equilibrium investment level is less than the second-best amount unless the latter is zero; and
- 4 depending on the parameter values, pricing based on a noisy-but-informative signal of returns either raises or lowers the equilibrium level of the buyer's investment and profits relative to pricing based on a perfectly uninformative signal.



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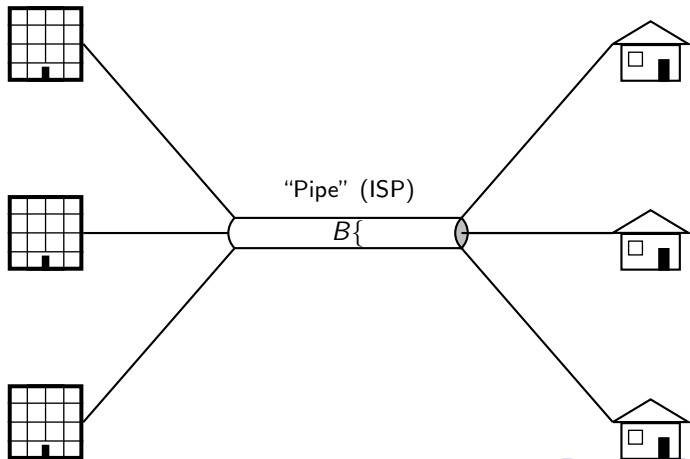
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# Economides and Hermalin (Work in Progress)

## Situation of Interest

Application Providers

Households



# Model

- Let  $B$  denote bandwidth.
- Two application providers.
- A continuum of households of measure one.
- Time to send  $Q$  packets is  $Q/B$ .
- Under **net neutrality** no priority and expected wait time for any one packet is  $\frac{1}{2} \times Q/B$ .
- Under discrimination (priority) there are two classes. If  $Q_k$  denotes the packets in class  $k$ , then the average waiting time for a packet in class  $k$  is

$$\bar{t}_k = \begin{cases} \frac{Q_1}{2B}, & \text{if } k = 1 \\ \frac{Q_2 + 2Q_1}{2B}, & \text{if } k = 2 \end{cases}.$$

# Households

- A household's expected benefit of trade with application provider  $n$  is

$$v_n - \omega_n \tau_n - p_n,$$

where  $v_n$  is value if delivery instantaneous,  $\omega_n \tau_n$  is the utility loss if expected delay is  $\tau_n$ , and  $p_n$  is application  $n$ 's price.

- $v_n \sim U[0, \bar{v}]$ , independent across providers and households.
- $\omega_2 > \omega_1$ .
- Application provider  $n$ 's demand is  $D_n(p) = 1 - \frac{p + \omega_n \tau_n}{\bar{v}}$ .
- Hence, inverse demand is  $P_n(q) = (1 - q)\bar{v} - \omega_n \tau_n$ .

# Net Neutrality

- Let  $c$  price per packet paid by application provider (AP) to ISP.
- AP  $n$ 's profit under net neutrality is

$$\pi_n(q_n) = \left( (1 - q_n)\bar{v} - \omega_n \frac{q_1 + q_2}{2B} - c \right) q_n.$$

- Observe APs are “quasi”-Cournot competitors.

# First Results

- $\omega_2 > \omega_1 \Rightarrow q_2 < q_1$ .
- $\omega_2 > \omega_1 \Rightarrow \pi_2(q_2) < \pi_1(q_1)$ .
- $q_1 + q_2 \propto \bar{v} - c$ . If ISP has constant  $MC = \gamma$ , then  $c = \frac{1}{2}(\bar{v} + \gamma)$ ; that is, ISP's price is independent of bandwidth or the cost-of-delay parameters.



# Price Discrimination

## Setup

- Consider 3rd-degree discrimination (ISP knows the  $\omega$ s).

## Results

- The ISP gives priority to firm 1 (recall  $\omega_1 < \omega_2$ ).
- Firm 1's profits greater under priority than net neutrality.
- Firm 2's profits greater under net neutrality than priority.
- Total packets sent greater under priority than net neutrality.
- The ISP's incentives to invest more in bandwidth can be greater under either priority or net neutrality.

# Obviously More to Be Done

- Other forms of price discrimination (2nd-degree).
- Have ignored pricing to households.
- Welfare analysis.

# Summary

- “Intuitive” arguments about the consequences of discriminatory pricing when parties invest — *à la* net-neutrality debate — are often incomplete and not infrequently wrong.
- The seller’s inability to commit not to price based on knowledge of buyer’s investment benefits the buyer and can be harmful to the seller.
- The consequences of more information are not necessarily monotonic.
- An important area in which much remains to be addressed.

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