Industry Equilibrium with Open Source and Proprietary Firms

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Introduction

- Open Source (OS): freedom to use, modify and copy source code.
- Important participation of profit-maximizing firms in OS.
- Coexistence of OS and Proprietary (P) firms.
- Questions:
  - What motivates firms to participate in OS?
  - What are the implications of competition?
  - Will OS or P have higher quality?
  - What are the limits to OS?

Some Important Characteristics of OS

General Public License and code sharing.

Firms profit by selling complementary goods.

- Red Hat: $650 million in training and support services in 2008.
- IBM: Invested $1 billion in Linux in 2001.
  Support for over 500 software products on Linux.
  Over 15,000 Linux-related customers.

Complementary goods are differentiated:

- Firms specialize in different technologies.
  Oracle: Linux support integrated with support for 11g database.
- Building a strong brand.
  Red Hat: strong trademarks policy.

Coexistence of OS and P

Software	Open Source	Proprietary
Operating Systems	Linux, OpenSolaris	Windows
Web browsers	Mozilla/Netscape	Internet Explorer
Web servers	Apache	MS Internet Information Server
Mail servers	Sendmail	IBM Lotus Domino, MS Exchange Server
Databases	MySQL, PostgreSQL	Oracle 11g, MS SQL Server
Content management	Plone	MS Sharepoint, Vignette
Application servers	JBoss, Zope	IBM WebSphere, MS .net
Blog publishing	WordPress	Windows Live Writer

Market Structure

Linux Market shares:

- Desktop: Linux below 10%.
- Servers: Linux + Unix $\geq$ 45%.
- Embedded: Linux 50% of cell phones.

Asymmetric Market Structure:

- Large P, small OS.
- Surveys: Seppä (2006), Bonaccorsi & Rossi (2004).

Related Literature

- Motivations of individual developers.
  (Lerner and Tirole 2002, 2005, von Krogh and von Hippel 2006)
- Competition between OS and P.
  (Mustonen 2003, Bitzer 2004, Gaudeul 2005, Casadesus-Masanell and Ghemawat 2006, Economides and Katsamakas 2006, Athey and Ellison 2010, Casadesus-Masanell and Llanes 2010)
  (Jansen 2009, Lambardi 2009, von Engelhardt and Maurer 2010)
- Contributions:
  - Endogenous decision to be OS.
  - Endogenous market structure.
  - Competition between profit-maximizing OS and P firms.
- Cooperation in R&D.
  (Kamien, Muller and Zhang 1992; Amir, Evstigneev and Wooders 2003)

Overview of the model

- Game: Two-stage non-cooperative game, *n* firms, continuum of consumers.
- Firms decide:
  1. To be OS or P.
  2. How much to invest in R&D and price.
- Difference: OS share R&D, P do not.
- Firms sell packages:
  1. Primary good (software), potentially OS.
  2. Complementary good (support and training).
- Vertical and horizontal differentiation.

Main Findings

- Equilibrium with both kinds.
  - Asymmetric market structure.
  - Few large P, many small OS.
  - P have higher quality.
- Other results:
  - Equilibrium with all OS: may have high or low quality.
  - Welfare analysis and government policy.

Extensions

We consider the following extensions:

- OS products are less differentiated than P products.
- Direct investment in the complementary good.
- Initial asymmetries in firm size.

Summary

Main ingredients:

- Industry equilibrium with OS and P firms.
- Firms sell packages with complementary good.
- Decision to be OS is endogenous.

Main results:

- Co-existence can arise as an equilibrium outcome.
- Forces leading to an asymmetric market structure.
- Complementarities may lead to high quality OS products.

Technology

- Fixed number of firms: n.
- Investment in R&D: x_i.
- Fixed cost: $F = c\,x_i$. Zero marginal cost.

- Packages: primary good and complementary good.

- Quality of primary good:

$$a_{os} = \ln(\Sigma_{i \in os}\, x_i) \quad \text{for OS firms}$$
$$a_i = \ln(x_i) \quad \text{for P firms}$$

- Quality of complementary good:

$$b_i = \ln(x_i) \quad \text{for all firms}$$

Preferences

- Continuum of consumers. Each consumer buys one package.
- Consumer *j*'s indirect utility from consuming good *i*:

$$v_{ij} = \alpha\, a_i + \beta\, b_i - p_i + \varepsilon_{ij}$$

- Vertical and horizontal differentiation.
- Taste shocks (ε_{ij}):
  - Each consumer has *n* shocks (one for each good).
  - ε_{ij} have double exponential distribution (logit model).
  - Variance: μ (degree of horizontal differentiation)

Parameters of interest

$$v_{ij} = \alpha\, a_i + \beta\, b_i - p_i + \varepsilon_{ij}$$

$$\delta = \frac{\alpha + \beta}{\mu} \qquad \gamma = \frac{\alpha}{\alpha + \beta}$$

δ: Importance of Vertical vs. Horizontal differentiation.

γ: Importance of Primary vs. Complementary good.

Assumption: $\mu > \alpha + \beta \implies \delta, \gamma \in [0, 1]$

Demands

- Consumer Problem:
  Observe a, b, p and choose package with highest indirect utility.
- Interested in Aggregate Consumer Demands
  (solve Consumer Problem and integrate across consumers)
- Demand for good i (market share):

$$s_i = \frac{\exp\left(\frac{\alpha\, a_i + \beta\, b_i - p_i}{\mu}\right)}{\sum \exp\left(\frac{\alpha\, a_i + \beta\, b_i - p_i}{\mu}\right)}$$

Game and Equilibrium Concept

- Players: n firms.
- Two-stage non-cooperative game:
  1. Firms decide to become OS or P.
  2. Firms decide investment in R&D and price.
- Subgame Perfect Equilibrium.
- Symmetric Equilibrium in Second Stage:
  All firms of the same type play the same equilibrium strategy.

Solution of the Second Stage I

- Recursive solution.
- n_{os}: number of firms deciding to be OS (given for 2nd stage).
- Second stage problem:

$$\pi_i = \max_{p_i,\, x_i \geq 0} \; s_i(p, x)\, p_i - c\, x_i$$

- Solution: $p_{os}, x_{os}, s_{os}, \pi_{os}$ and p_p, x_p, s_p, π_p as functions of n_{os}.

Solution of the Second Stage II

From FOC and imposing symmetry:

Profit maximizing price:

$$p_{os} = \mu \frac{1}{1 - s_{os}} \qquad p_p = \mu \frac{1}{1 - s_p}$$

Investment in R&D:

$$x_{os} = \frac{\alpha + \beta}{c} s_{os} \left(1 - \gamma \frac{n_{os} - 1}{n_{os}(1 - s_{os})}\right)$$

$$x_p = \frac{\alpha + \beta}{c} s_p$$

Substituting x (which determines a and b) and p into demands $s_i(p, x)$, we get a system of equations determining $s_{os}(n_{os})$ and $s_p(n_{os})$.

Second Stage Equilibrium

Proposition:

Second-stage equilibrium exists and is unique.

Given n_{os}, market shares solve $(n - n_{os})\, s_p + n_{os}\, s_{os} = 1$ and:

$$(1-\delta)\ln\left(\frac{s_{os}}{s_p}\right) + \frac{1}{1-s_{os}} - \frac{1}{1-s_p} = \delta\,\ln\left(1 - \gamma\,\frac{n_{os}-1}{n_{os}(1-s_{os})}\right) + \delta\,\gamma\,\ln(n_{os})$$

Interpretation:

$$g(s_{os}, s_p) = \underbrace{\ln\left(1 - \gamma\,\frac{n_{os}-1}{n_{os}(1-s_{os})}\right)}_{\text{Free-riding}} + \underbrace{\gamma\,\ln(n_{os})}_{\text{Collaboration}}$$

Second Stage: Bottom line

- Existence and uniqueness.
- s_{os} and s_p as functions of n_{os}
- Free-riding vs. Collaboration.
- π_{os} and π_p as functions of n_{os}

Solution of the First Stage

Profits:

$$\pi_{os}(n_{os}) = \mu \frac{s_{os}}{1 - s_{os}} \left(1 - \delta(1 - s_{os}) + \delta\gamma \frac{n_{os} - 1}{n_{os}}\right)$$

$$\pi_{p}(n_{os}) = \mu \frac{s_{p}}{1 - s_{p}} \left(1 - \delta(1 - s_{p})\right)$$

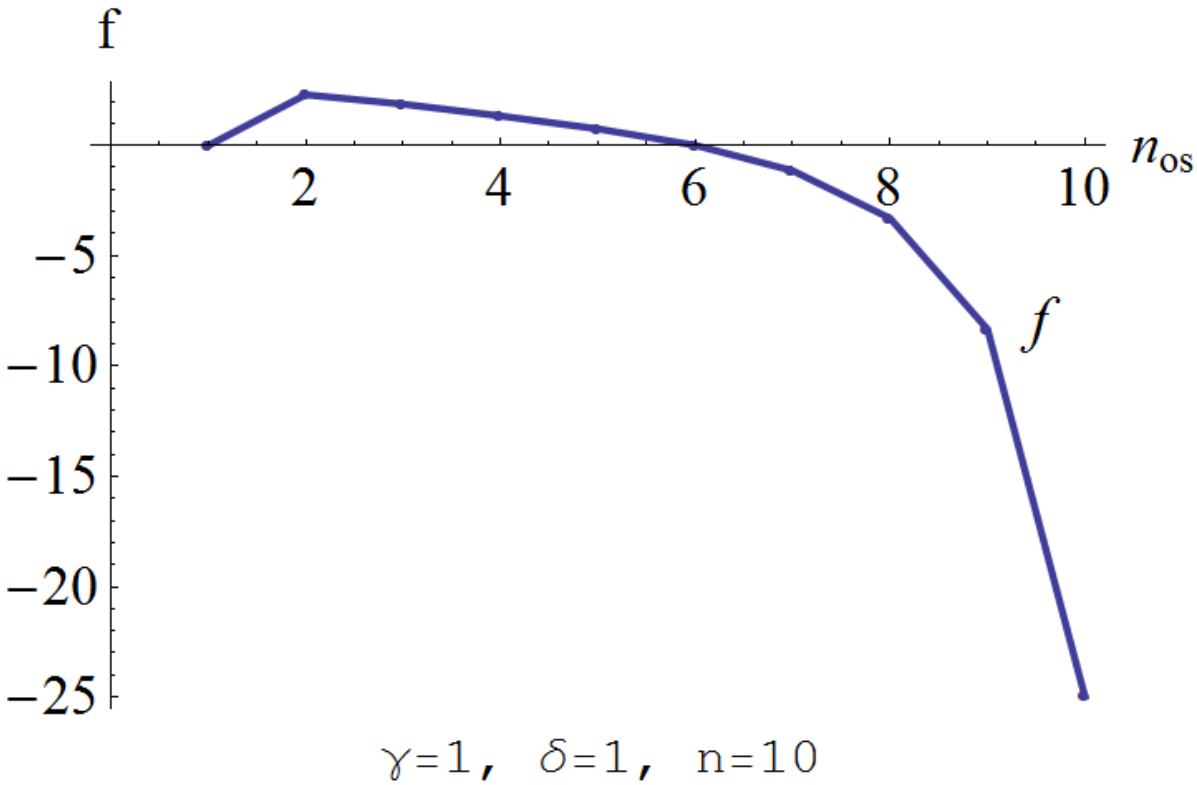
Equilibrium:

$$\pi_{os}(n_{os}) \geq \pi_{p}(n_{os} - 1) \qquad \pi_{p}(n_{os}) \geq \pi_{os}(n_{os} + 1)$$

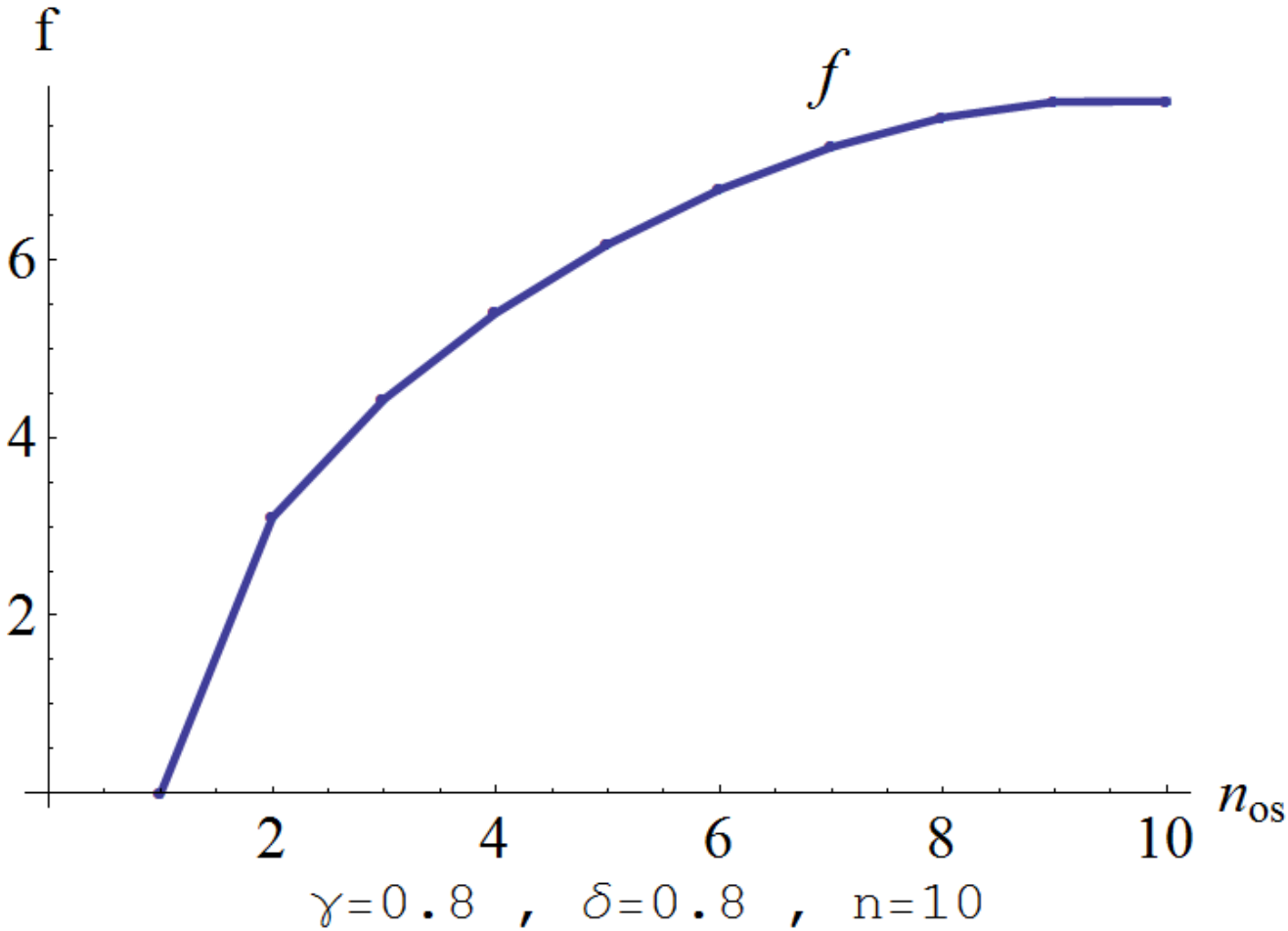
In terms of $f(n_{os}) = \pi_{os}(n_{os}) - \pi_{p}(n_{os} - 1)$:

$$f(n_{os}) \geq 0 \qquad f(n_{os} + 1) \leq 0$$

Co-existence Equilibrium.



All OS Equilibrium.



Solution of the First Stage

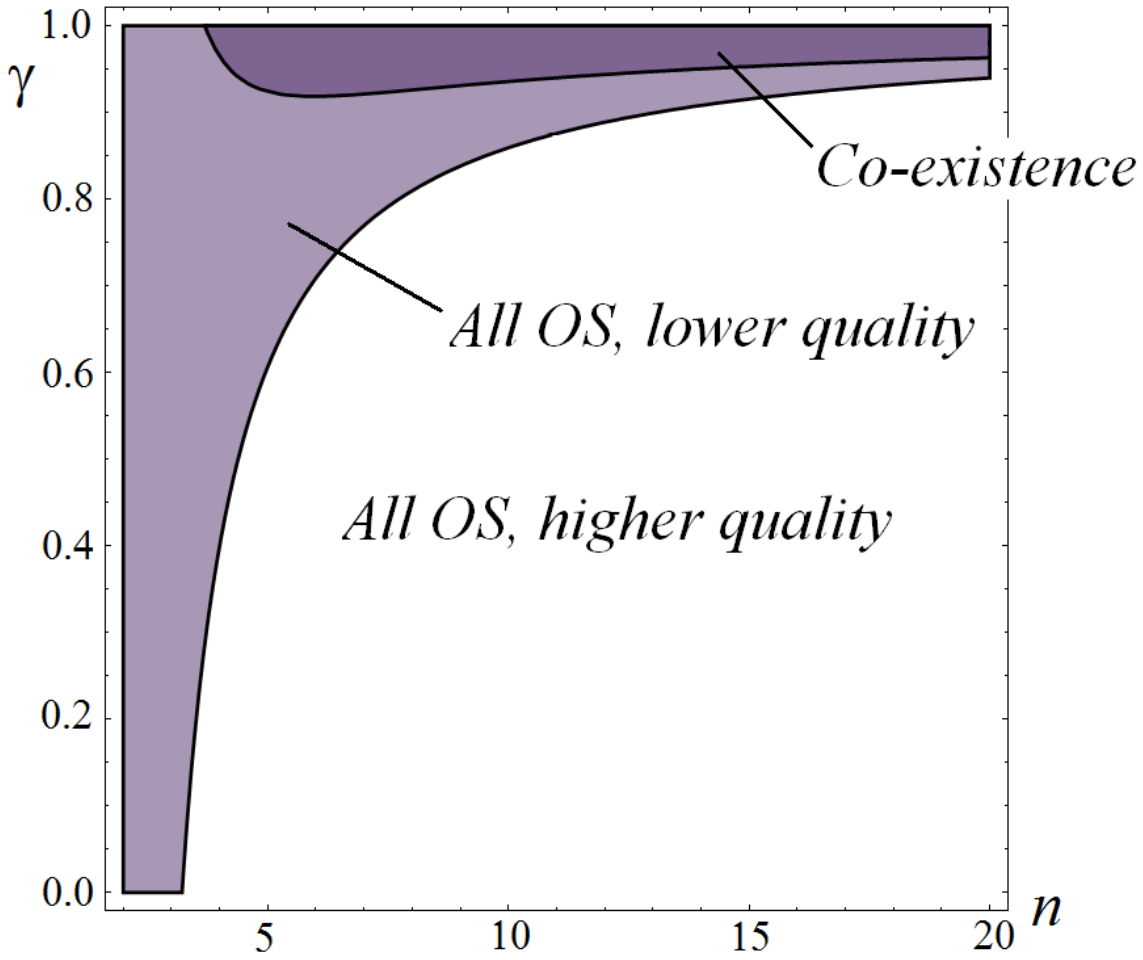
Proposition:
Given $n > 3$ and δ, there are values $0 < \bar{\gamma} < \hat{\gamma} < 1$ such that:

$\gamma > \hat{\gamma}$ { Both kinds of firms co-exist in equilibrium. P have higher quality and market share than OS.

$\bar{\gamma} < \gamma < \hat{\gamma}$ { All firms are OS. P would have higher quality and market share.

$\gamma < \bar{\gamma}$ { All firms are OS. P would have lower quality and market share.

Equilibrium Regions



Conclusion

Main ingredients:

- Model of industry equilibrium with OS and P firms.
- OS profit from selling a complementary good.
- Decision to be OS is endogenous.

Main results:

- Co-existence can arise as an equilibrium outcome.
- Decision to be OS: optimal business strategy.
- Forces leading to an asymmetric market structure.
- Complementarities may lead to high quality OS products.
- Testable implications.

Thank you!

Importance of commercial firms in OS

- Embedded Linux: 73.5% of developers work for commercial firms, and contribute 90% of code (Henkel and Tins 2004).
- 55% of OS developers contribute code at work, and contribute 50% more hours than the rest (Lakhani and Wolf 2005).
- 30% of OS developers work for commercial firms, and these firms are associated with larger and more dynamic OS projects (Lerner, Pathak and Tirole 2006).

Complementarities in OS

- Embedded Linux: 51.1% of developers work for manufacturers of devices, chips or boards and 22.4% work for specialized software companies (Henkel and Tins 2004).
- The dominant trend for appropriating the returns of innovation in OS is the sale of a complementary service (Dahlander 2004).

Derivation of Demand

Assumption

ε_{ij} are i.i.d. and follow a double exponential distribution:

$$\Pr(\varepsilon_i < \omega) = \exp\left(-\exp-\left(\frac{\omega}{\mu}+\nu\right)\right)$$

where ν is Euler's constant and μ is a non-negative constant.

$$s_i = \text{measure of consumers for which } v_{ij} = \max\{v_{1j},\ldots,v_{nj}\}$$

$$s_i = \Pr\left(v_{ij} = \max\{v_{1j},\ldots,v_{nj}\}\right)$$

▸ Back to Consumer Preferences

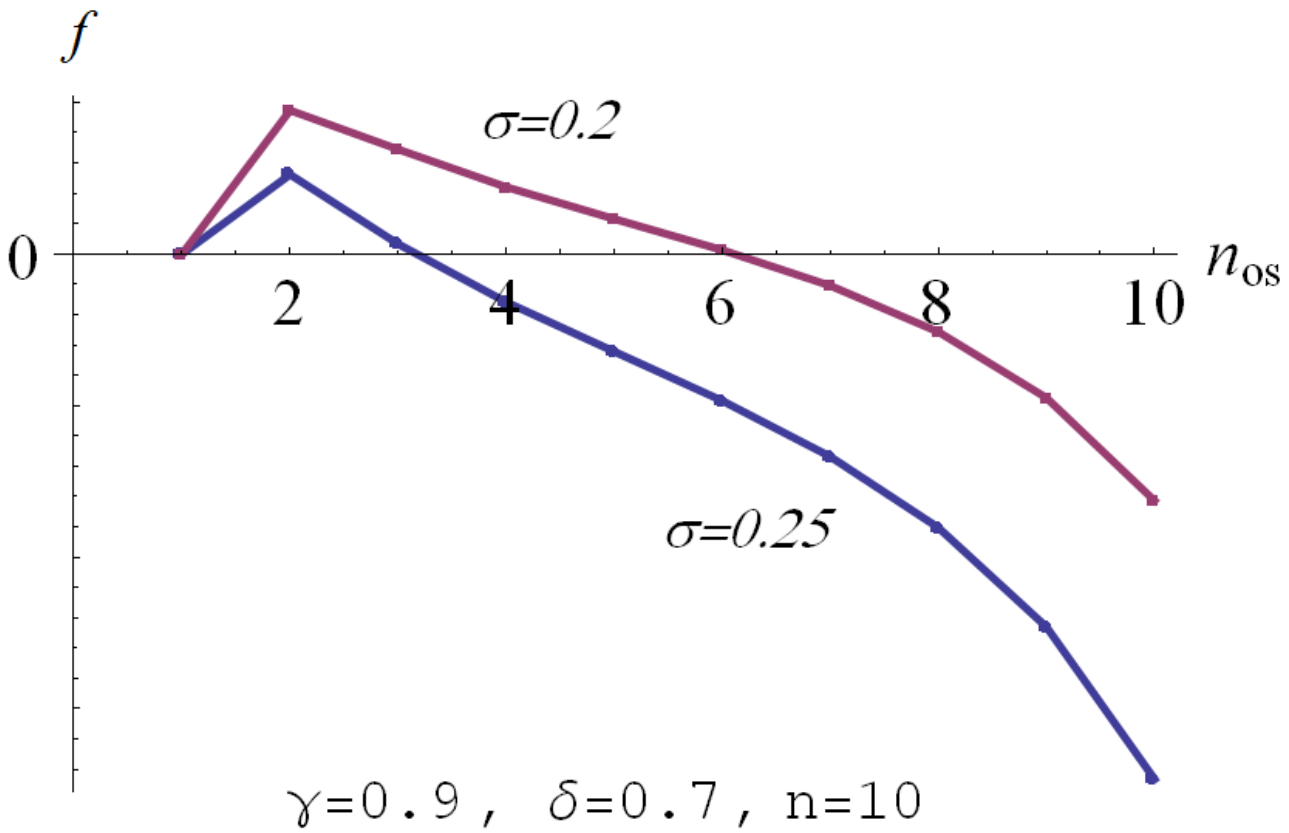
OS are less differentiated than P.

- New dimension: Endogenous product differentiation.
- Two consumer shocks:
  1. Primary good shock.
  2. Complementary good shock (same as before).

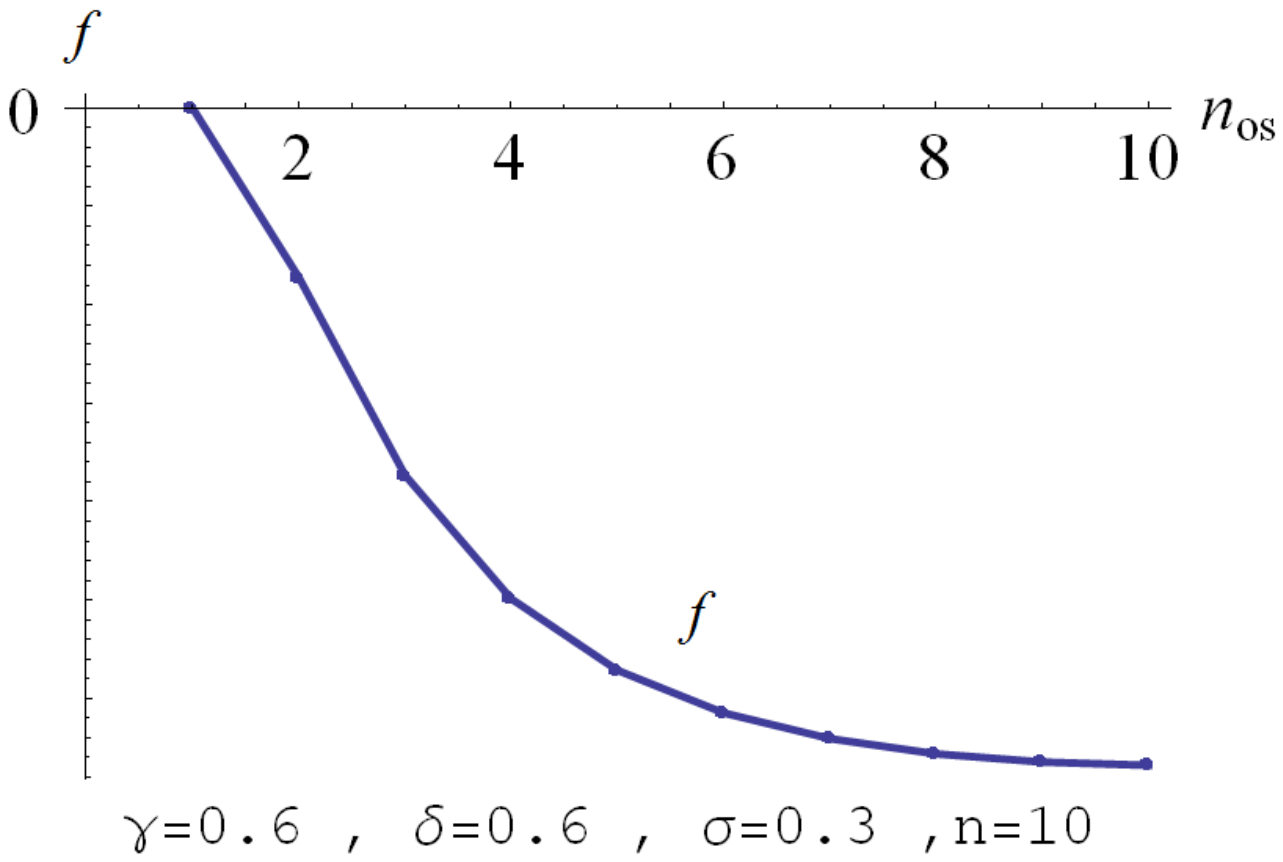
$$v_{ij} = \alpha\, a_k + \beta\, b_i - p_i + \sigma\, \eta_{kj} + (1-\sigma)\, \varepsilon_{ij}$$

σ: horizontal differentiation of primary vs. complementary good.

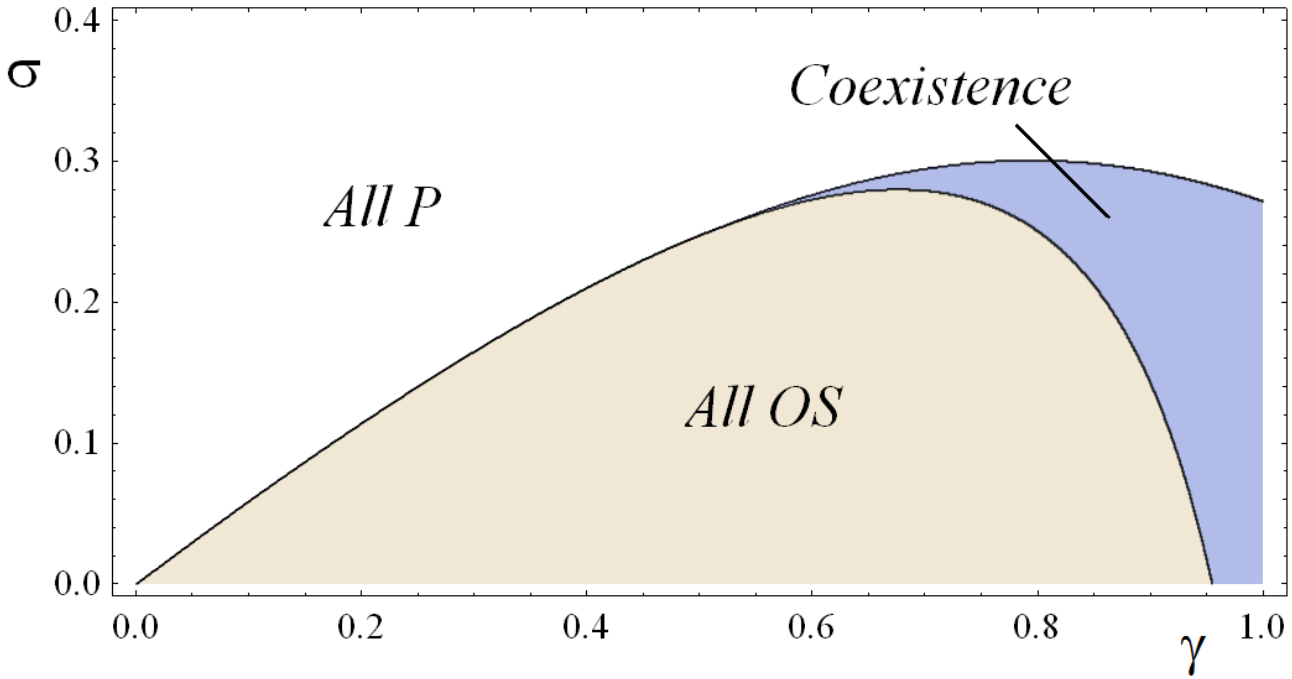
Effect of an increase in σ



All P Equilibrium



Equilibrium regions



Direct investment in the complementary good.

- Firms can increase the value of the complementary good, without increasing the value of the primary good.
- Quality of complementary good:

$$b_i = \omega \ln(x_i) + (1 - \omega) \ln(z_i)$$

- z_i: direct investment in the complementary good.
- As ω decreases, investment of OS firms decreases.

Effect of an increase in ω