# Digital Convergence, Product Architecture and Market Structure

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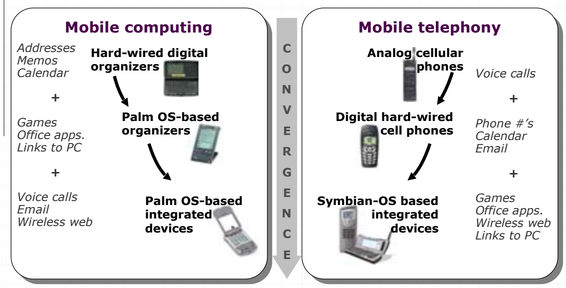
## Digital Convergence: Overview




Key technological drivers of convergence

- Widespread digitization of product technologies and content
- Increasing power and miniaturization of semiconductor components
- Shift to platform-based architectures (hardware->OS->applications)



## Digital Convergence: Overview

Examples of converging products and services

- **Mobile devices:** Wireless telephony, mobile Internet and handheld computers (Palm, Symbian)
- **Consumer electronics:** Home entertainment systems, video game consoles, and home computers (X-Box, Digeo, Sony)
- **Residential communications:** Broadcast video, Internet access and wireline telephony (cable modems, DSL)
- **Networking equipment:** Layer-3 switches (routers)

Key technological drivers of convergence

- Widespread digitization of product technologies and content
- Increasing power and miniaturization of semiconductor components
- Shift to platform-based architectures (hardware->OS->applications)



## Digital Convergence: Overview

### Primary economic trade-off

- Products become more valuable
  - Fulfill larger set of consumer needs
  - Sometimes fulfill them better
- Products become closer substitutes
  - Increased flexibility – adding applications
  - Overlap in delivered functionalities



## Research Agenda

- Explore the trade-off between value and substitutability in converging technology markets
- Characterize the nature of outcomes as distinct technology markets overlap
  - structure of equilibrium configurations
  - prices and consumption patterns
  - profits and surplus distribution
  - investment levels in platform scope
- Study the impact of changes in
  - breadth of consumer requirements
  - cost structure (variable, fixed)



## Snapshot of Results

As technology markets converge:

- Higher prices and profits possible, despite *reduced* product differentiation
- Strategic choices of product scope prevent commoditization and Bertrand outcomes
- Distortions in investment incentives are positive when markets are fully covered
- Consumption patterns may be altered
  - multiple products $\rightarrow$ fewer products $\rightarrow$ multiple products.

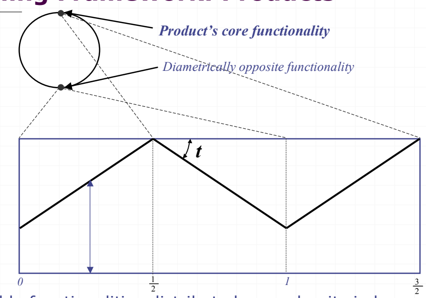
## Modeling Framework

Model needs to be able to:

- Represent set of relevant *functionalities*
- Allow variable and possibly endogenous fulfillment of functionalities by products
- Admit varying sets of consumer requirements
- Allow consumers to make either discrete or multiple purchases to fulfill requirements



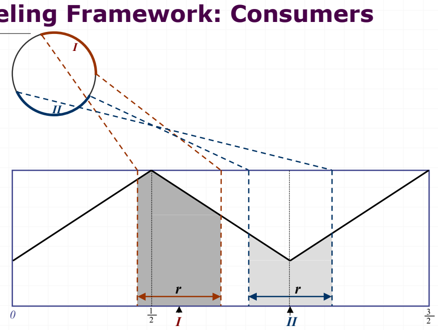
## Modeling Framework: Products




- Feasible functionalities distributed around unit circle
- Product defined by
  - Location of core functionality
  - Level of platform scope (***1/t***), exogenous loss function ***g(x)***
- Products provide functionalities with varying effectiveness



## Modeling Framework: Consumers

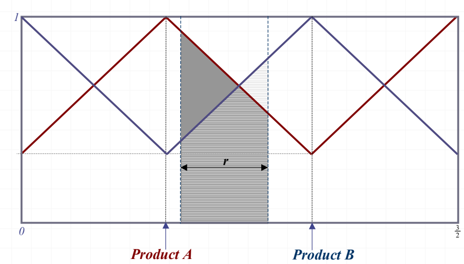



Continuum of heterogeneous consumers

- Require different sets of functionalities
- Have same breadth of functionality requirements ***r***
- Uniformly distributed around unit circle



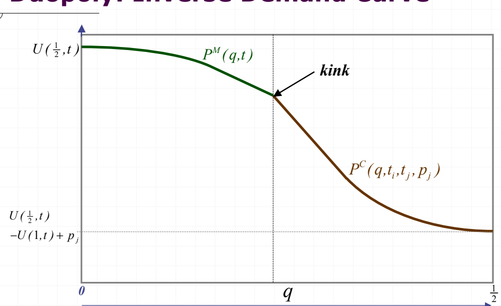
## Duopoly: Model Specification




- Two single-product firms – diametrically opposite locations
- Linear loss function ***g(x)=x***
- Game structure
  a. Symmetric exogenous scope, simultaneously choose prices
  b. Two-stage game – endogenous scope, then prices



## Duopoly: Inverse Demand Curve




- Distinct 'monopoly' and 'competitive' regions
- Demand is less elastic in the competitive region
- Location of kink driven by opponent's price



## Duopoly: Some analytical details

1. Utility functions

$$U(y,t)=\int_{y-\frac{r}{2}}^{\frac{1}{2}}(1-tg(\tfrac{1}{2}-x)dx+\int_{\frac{1}{2}}^{y+\frac{r}{2}}(1-tg(x-\tfrac{1}{2})dx \quad for \quad \tfrac{1}{2}\le y\le \tfrac{1+r}{2}$$

$$U(y,t)=\int_{y-\frac{r}{2}}^{y+\frac{r}{2}}(1-tg(x-\tfrac{1}{2})dx \quad for \quad \tfrac{1+r}{2}\le y\le 1-\tfrac{r}{2}$$

$$U(y,t)=\int_{y-\frac{r}{2}}^{1}(1-tg(x-\tfrac{1}{2})dx+\int_{1}^{y+\frac{r}{2}}(1-tg(\tfrac{3}{2}-x)dx \quad for \quad 1-\tfrac{r}{2}\le y\le 1$$

2. Inverse demand curves

$$P^M(q,t)=U(q+\tfrac{1}{2},t);\ \ P^C(q_i,t_i,t_j,p_j)=U(q_i+\tfrac{1}{2},t_i)-U(1-q_i,t_j)$$

3. Second-stage payoff functions

$$\pi(q_i,t_i,t_j,p_j)=nq(P^M(q,t)-c)\ \textbf{or}\ \ \pi(q_i,t_i,t_j,p_j)=nq(P^C(q_i,t_i,t_j,p_j)-c)$$

4. Interior local maxima

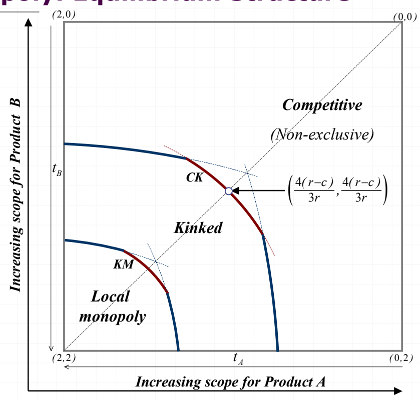
$$Q^M(t_i)=q:q=\frac{U(q+\frac{1}{2},t_i)-c}{-U_1(q+\frac{1}{2},t_i)};\ Q^C(t_i,t_j)=q:q=\frac{U(q+\frac{1}{2},t_i)-c}{-[U_1(q+\frac{1}{2},t_i)+U_1(1-q,t_j)}$$

5. Equilibrium configurations

***Local Monopoly:*** $Q^M(t_i)+Q^M(t_j)\le\frac{1}{2}$; ***Competitive:*** $Q^C(t_i)+Q^C(t_j)\ge\frac{1}{2}$;

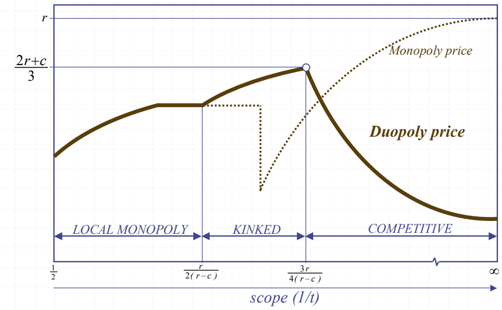
***Kinked:*** $Q^M(t_i)+Q^M(t_j)\ge\frac{1}{2}$ ***and*** $Q^C(t_i)+Q^C(t_j)\le\frac{1}{2}$

## Duopoly: Equilibrium Structure





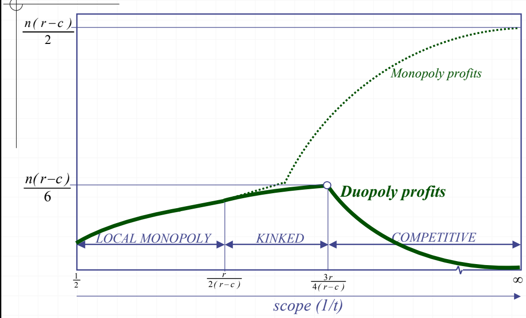

## Duopoly: Equilibrium Prices




- Initially, prices increase despite decreasing differentiation
- Prices higher than corresponding monopoly price
- Endogenous-scope price = highest possible duopoly price



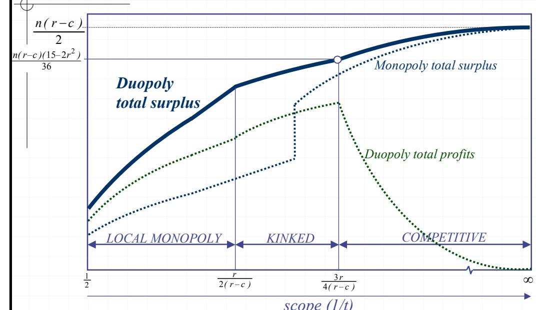
## Duopoly: Profits




- Profits increase initially even after market is fully covered
- When platform scope is very high, competition → Bertrand
- Endogenous-scope profits = highest possible duopoly profits



## Duopoly: Surplus




- Total surplus always higher under duopoly than monopoly
- Consumer surplus declines in kinked region, rises otherwise
- Endogenous-scope CS = lowest duopoly CS with full coverage



## Summary of Key Results

- In the earlier stages of convergence (kinked)
  - Prices increase even as products become less differentiated
  - Prices are higher than corresponding monopoly prices
  - Firms can therefore appropriate surplus created by increased platform scope and product value
- In later-stage convergence (competitive)
  - Prices, profits fall rapidly as platform scope increases
  - Consumers realize all the surplus (and more) created by increased platform scope and product value
- Therefore, in the trade-off central to converging markets:
  - Value increases dominate initially (kinked configuration)
  - Substitutability dominates subsequently (competitive configuration)
- If scope can be chosen strategically, all sub-game perfect equilibria preserve high prices and profits.



## Further Results

- As the breadth of consumer requirements increases, prices and profits increase for all values of scope
  - Highlights the importance of separating consumer parameters from product variables
- As variable costs fall, exogenous-scope prices
  - decrease under local monopoly and competitive equilibria
  - remain constant under kinked equilibria
- Kinked equilibrium outcome is subgame perfect, 'standard' competitive outcome is not.
- Relative to social optimum, in both monopoly and duopoly
  - Firms under-invest in scope when market is partially covered
  - Firms over-invest in scope when market is fully covered
- For broad consumer requirements, permitting non-exclusive choice leads to a new kind of outcome
  - Multiple products → one product → multiple products

## Ongoing Work

- Endogenize choice of effectiveness on core functionality in addition to scope
- Incorporate intra-industry competition by having more than one firm at a single location
- Generalization to multi-dimensional functionality spaces



## Questions?