Cross-Product Compatibility, Lock-In, and Market Power: The Case of Smartphones and Laptops

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Introduction

March 21, 2024 The New York Times

U.S. Sues Apple, Accusing It of Maintaining an iPhone Monopoly

The lawsuit caps years of regulatory scrutiny of Apple's wildly popular suite of devices and services, which have fueled its growth into a nearly $3 trillion public company.

Dec 18, 2024 European Commission

Commission adopted its preliminary findings setting out the proposed measures that Apple should implement to ensure effective interoperability.

"The interoperability solutions for third parties will have to be equally effective to those available to Apple and must not require more cumbersome system settings or additional user friction."

- Cross-product compatibility- features allowing consumers to connect products seamlessly
- Example: copy-paste across devices
- Firms use compatibility to maintain their market power

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"*Tie all of our products together, so we further lock customers into our ecosystem*" (*S. Jobs, Apple* former CEO)

Research question

In the U.S. smartphone and laptop markets-

- How does opening firms' closed ecosystems affect welfare?
- What is the welfare effect of the Samsung-HP cross-market merger?

→ The effect on welfare is ambiguous
- expansion in compatible product variety[1]
- prices may increase (e.g., market concentration increases)

[1] Compatibility across brands is first shown to be possible in 2021, when Apple allows FaceTime to connect with non-Apple smartphones.

Empirical strategy

1. Recover the causal effect of compatibility on demand through an incentivized experiment
   - Modified Becker et al. (1964); Coffman and Niehaus (2020) to elicit true WTP

Results: compatibility with laptops increases the WTP for smartphone by 9% of its retail price

2. Model: Smartphone demand incorporating cross-product compatibility with owned laptops, treated as a state variable

3. Counterfactuals
   - open ecosystem
   - Samsung-HP cross-market merger

Contribution

1. Methodological improvement

Pakes (2021): *[Structural models have] "difficulty distinguishing between correlations in tastes and causal factors that lead to similar actions."*

- market data cannot distinguish compatibility from other effects, e.g., correlation, brand loyalty
  - goods not purchased simultaneously
  - goods not purchased frequently
  - characteristics change over time
- Cannot use Ershov et al. (2024) who provides suggestive spatial evidence using market data
- Novel incentivized experimental methodology that allows identifying parameters causality

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Contribution

2. Product compatibility
   - software and hardware in US video game (Lee, 2013)
   - cameras and lenses (Huang, 2022)
   - electric vehicles and charging stations (Li, 2023)

- Reveals compatibility impacts *stand-alone* products (brand pref. & loyalty ↓)

→ dependency of tech markets (Goeree, 2008; Eizenberg, 2014; Fan and Yang, 2020)
  - welfare trade-offs arising from closed ecosystems

→ firms exacerbate power across (ostensibly) independent markets

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[2] Heidhues et al. (2024) provides a theoretical model of digital ecosystems, emphasizing how firms with cross-market leverage, especially those controlling access points, expand through strategic takeovers and steer users across markets.

[3] Bursztyn et al. (2025) shows that Apple uses ecosystem design to reduce non-user utility and shape demand within the smartphone market.

Experiment

- Data: smartphone and laptop brand purchases positively correlated conditional probability
- What causes this correlation? Compatibility?
- Reasons compatibility may not affect purchases
  - prices are independent of compatibility
  - no evidence compatibility ties consumers to stand-alone products

Goal: Disentangle compatibility effect

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Design outline

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Demand

- Smartphone market
- Random-coefficient static discrete choice model
- Indirect utility for consumer i from smartphone $j \in S$ when own laptop $c \in C$ (c taken as given)

$$u_{ij}(x_j, q_{jc}) = \sum_{k=1}^{K} x_{jk}\beta_{ik} + \sum_{g=1}^{G} q_{jcg}\Gamma_{ig} + \lambda_{fj} + \alpha_i p_j + \xi_j + \epsilon_{ij} \quad (1)$$

- x_{jk} product characteristics independent of c
- q_{jcg} compatibility index depends on j and c
- λ_{fj} firm f FE
- ξ_j product j unobservable characteristics
- ϵ_{ij} mean zero idiosyncratic consumer-product specific term
- β_{ik} individual-specific taste for independent cross-market product characteristics k
- Γ_{ig} individual-specific taste for dependent cross-market product characteristics g

Composite I Composite II

Supply

- F firms, each producing a subset of the S smartphones
- Pure-strategy, Nash–Bertrand price eqm.
- Firm $f \in F$ maximizes profit $w.r.t\ p_j$ mc

$$\max_{p_j} \pi^f = \sum_{j \in S^f} \left[p_j - mc_j\right] s_j(p) \times M \tag{2}$$

  - S^f are smartphones firm f produces.

- Large product variety, consumer heterogeneity via RC & product compatibility, endogenous product
- Following Fan and Yang (2020) analyzing the smartphone market assuming static pricing

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Firm profit problem

Conditional on complementary market

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Across time within market

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Firm profit problem

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Across time
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Estimation- GMM

- Identification
  - Γ- for a given $j \in S$, variation in pre-owned laptop c
- Uniqly to the IO literature, moment uses experimental results, WTP for compatibility $\approx$ \$74
  - $Cov(q_{(j,c)} - q_{(j,c')}, \Delta WTP)$, i.e., heterogeneity in preferences for compatibility
    - Todd and Wolpin (2023) reviews labor literature on merging experimental results with structural models

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[4] This is equivalent to $E(q_{(j,\cdot)} \times \Delta WTP | q_{(\cdot,c)}) - E(q_{(j,\cdot)} | q_{(\cdot,c)}) E(\Delta WTP | q_{(\cdot,c)})$.

Est. results

Table 1: Smartphone Estimation Results elasticity Model fit

Variable	Parameter	SE
Individual level coefficient		
Price/income	-89.8156	25.9172
Compatibility	3.5956	1.4458
Common coefficient		
Screen size	1.6693	0.2035
Megapixels	0.0063	0.0033
Storage	0.0116	0.0018
Processor speed	1.6956	0.3996
Processor cores	0.1220	0.0635
Apple	2.9187	0.6106
Samsung	1.7685	0.2105
LG	0.1565	0.2308
Absorb Year FE	Yes	
Random coefficient		
Compatibility product	4.1457	1.3138

Note: "Compatibility product" is the maximum potential compatibility index in a device.

Variable	Parameter	SE
Marginal cost ($)		
Screen size	317.2009	0.1138
Megapixels	91.1382	0.3650
Storage	90.6937	0.0062
Processor speed	332.3779	0.0017
Processor cores	113.8479	0.4760
Absorb Year FE	Yes	

What is the welfare effect of open ecosystems?

- $q_{jc'} = \max\{q_{j\cdot}, q_{\cdot c'}\}$ forces
- Annual average effect across firms: price decreases, CS increases

Table 2: Open Ecosystems - Average Firm Effect Across Years

Firm	ΔInside good share	ΔSmartphone price	ΔFirms profit	ΔCS
Apple	0.0287			
LG	0.0229	-13.76		7,804
Motorola	0.0497	-10.23		7,496
Samsung	0.0674	-14.23		9,487

Note: Profit and CS are in millions.

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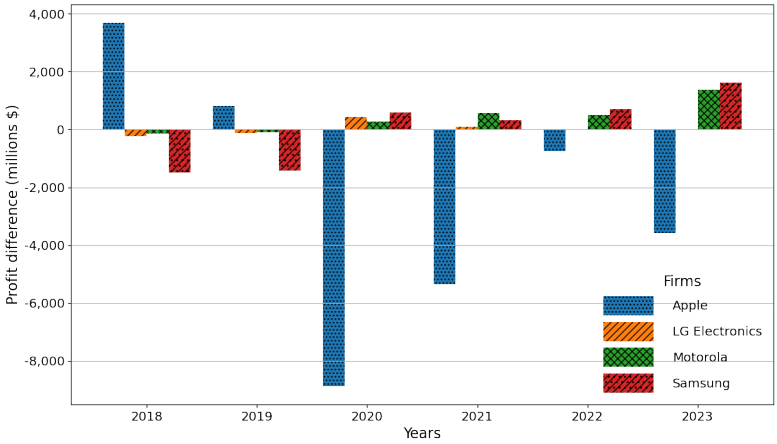
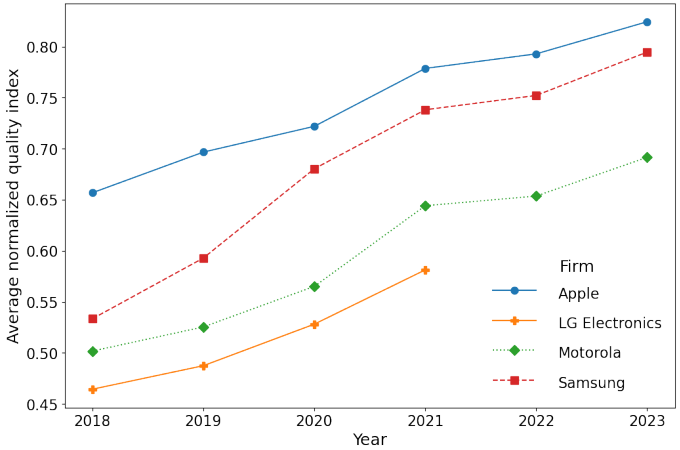
Figure 1: Open Ecosystem – Yearly Profit Differences by Firm



- 2020-2023: Apple main price drop

Open ecosystems effect depends on hardware quality

Figure 2: Smartphone Average Hardware Quality by Year



- Product characteristics (x) linear combination weighted by coefficients
- Non-Apple laptop: move to Apple ($q^{\uparrow}$)

  $\rightarrow \pi^{Apple}$ & market concentration $\uparrow$
- Apple laptop: move to Samsung ($\overline{q}$)

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  $\Rightarrow$ Regulator: can condition on quality gap.
- Regulator allowing min compatibility ($q_{jc'} = \min\{q_{j.}, q_{.c'}\}$) $\rightarrow$ Apple is better off, $\nexists$ switches away

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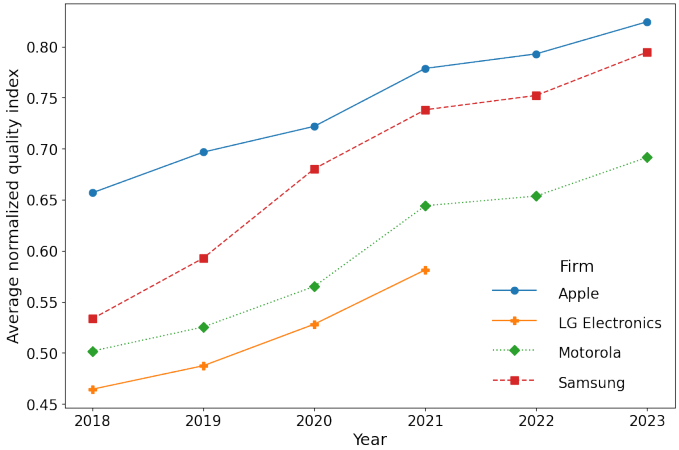

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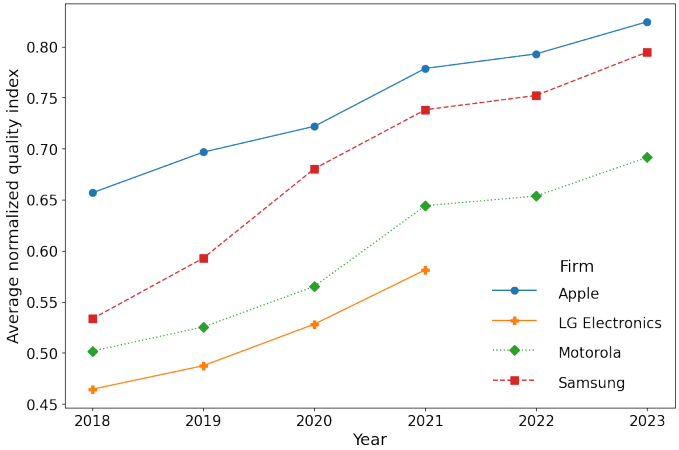

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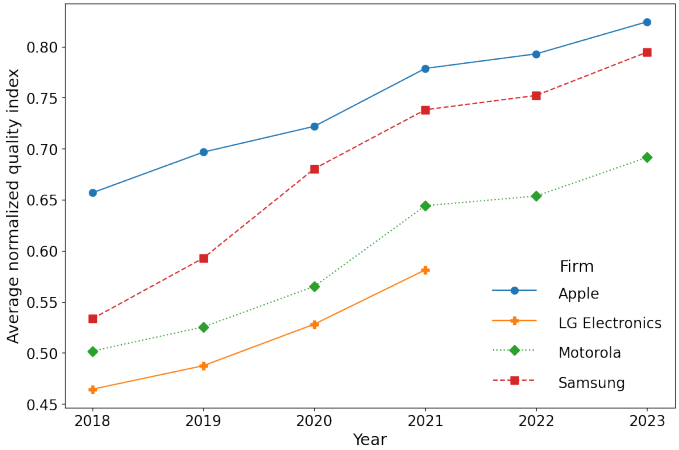

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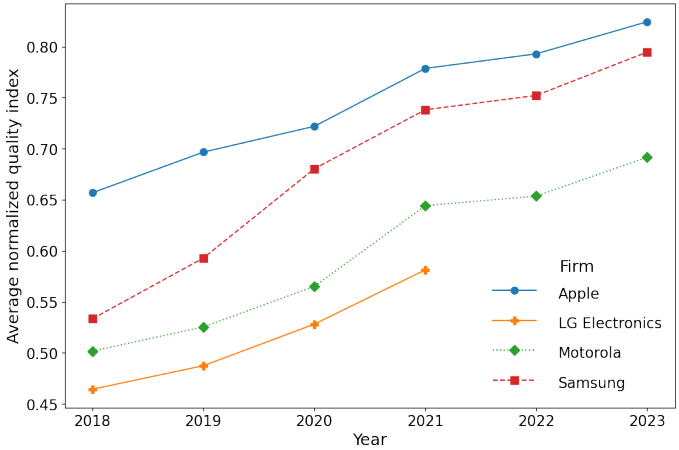

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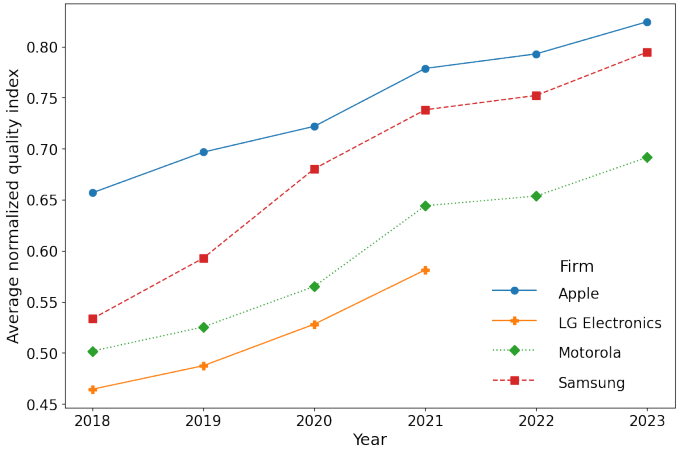

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What is the welfare effect of the Samsung-HP cross-market merger?

- Maximum compatibility

Table 3: Samsung-HP Merger - Average Firm Effect Across Years

Firm	ΔInside good share	ΔSmartphone Price	ΔFrims profit	ΔCS
Apple			-9,140	981
LG			-305	2,414
Motorola			-342	1,923
Samsung			11,012	2,164

Note: Profit and CS are in millions.

- HP laptop: move to Samsung ($q\uparrow$)
- Market concentration decreases (HHI -151, -3%) but $p_{Samsung-HP}\uparrow$
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Takeaway/Work in progress/Caveats

Takeaway

- Methodology identifying deep parameters causality
- Compatibility matters even in standalone products
- Open ecosystems & mergers can reduce market concentration & increase CS through compatibility

Work in progress/caveats

- While not analyzing laptop market conditional on smartphone– the results depends on quality gap
- "The effect of closed ecosystems on consumers' consideration sets" (with Lucas Coffman)
- "Open ecosystem effect on firm's investment choice"

Future

- More research is needed on the compatibility of standalone products
  - other tech markets
  - network effect (Bursztyn et al., 2025)

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Thank you!

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