WELFARE GAINS FROM PRODUCT & PROCESS INNOVATIONS:
THE CASE OF LCD PANELS, 2001–2011

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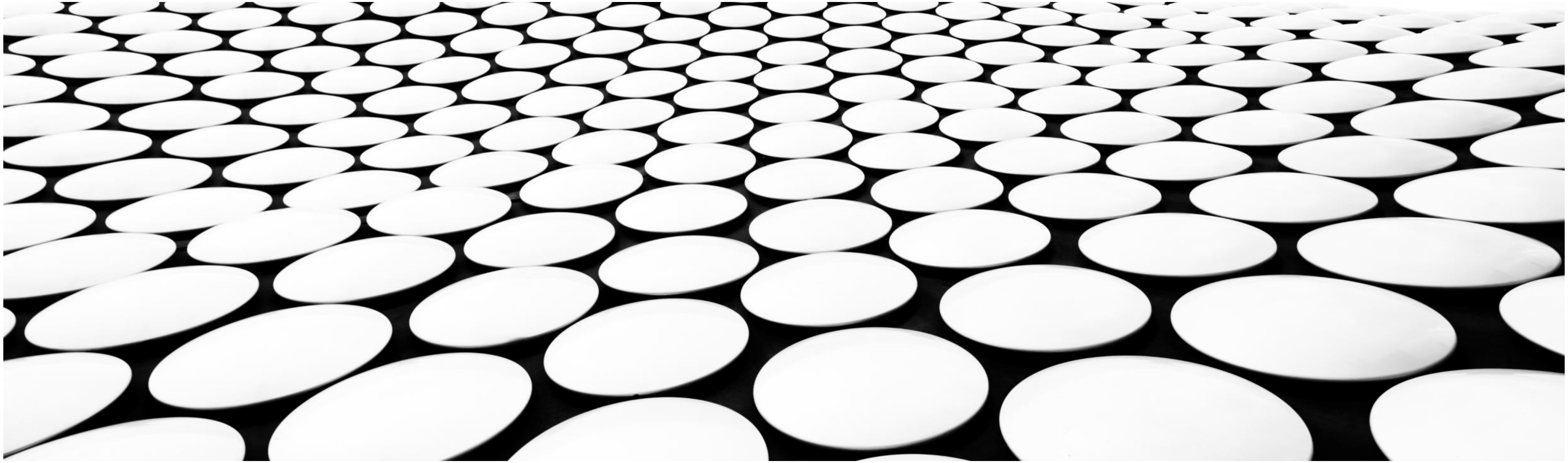


RESEARCH QUESTION:
HOW BIG IS THE WELFARE CONTRIBUTION OF INNOVATIONS?

- Innovation & productivity growth
  - Pivotal to welfare
    - Hard to measure (convincingly)
  - Recent IO: the power of new technologies, rediscovered
    - Ganapati ('21); Grieco, Murry, & Yurukoglu ('23); Miller, Osborne, Sheu, & Sileo ('23)
  - Renewed public-policy interests
    - US Merger Guidelines ('23), Japan Fair Trade Commission ('24)
    - Are mergers good for innovation?

LITERATURE (1 OF 3): PRODUCT INNOVATION

- Value of new goods
  - Long tradition
    - Griliches (‘57), Trajtenberg (‘89), Hausman (‘96), Greenstein (‘96), Petrin (‘02)
    - Eizenberg (‘14); Ciliberto, Moschini, & Perry (‘19); Grieco, Murry, & Yurukoglu (’23)
  - Use *sales* data
    - …to estimate a demand model for differentiated goods
    - = prerequisite to valuing new products
  - Issue: Without data on *costs* or *investments*, cannot measure:
    - Process innovation
    - Benefits vs costs—Returns on investment (ROI)

LITERATURE (2 OF 3): PROCESS INNOVATION

- Many determinants of productivity, but
  - "The relative quantitative importance of each, however, is still unclear" (Syverson '11, p. 358)
  - Use *census* data
    - ...to estimate revenue-TFP
  - Issues: Cannot measure:
    1. True, physical TFP
    2. Welfare gains
    3. Their determinants

LITERATURE (3 OF 3): COMPETITION & INNOVATION

- Biggest literature in economics
  - Many surveys
    - Gilbert ('06, '20); Cohen ('10); Shapiro ('12); Federico, Scott Morton, & Shapiro ('20)
    - Bryan & Williams ('21); Griffith & Van Reenen ('23); Lefouili & Madio ('24)
  - Modeling challenge—Realism vs. tractability
    - Recent advances clarify & narrow the range of plausible results: Marshall & Parra ('19); Igami & Uetake ('20)
    - IO of innovative industries, using dynamic structural models: Goettler & Gordon ('11); Conlon ('12); Igami ('17, '18); Björkegren ('19); Yang ('20); Mohapatra & Zhang ('23); Khmelnitskaya ('23); Qiu ('23)
  - Measurement challenge
    - *Good, bad, & ugly ways* to measure innovation (see previous pages)
    - *Good, bad, & ugly ways* to measure competition (e.g., Miller et al. '22)

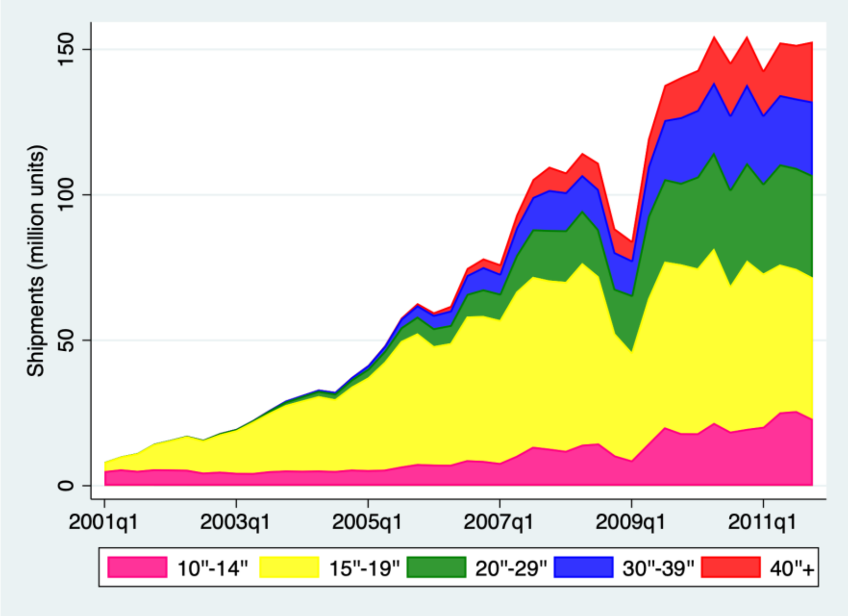
THIS PAPER:
GOOD DATA (& SIMPLE MODEL) SOLVE MOST PROBLEMS

- How far can we go in measuring:
  1. Welfare effects of innovations,
  2. Firms' incentive to innovate, &
  3. Effects of competition on innovation?

...in a global high-tech context of...

LIQUID CRYSTAL DISPLAY—WHY LCD?
(1) WIDELY USED, (2) LOTS OF INNOVATIONS, (3) AMAZING DATA

Larger new products



Rapid cost reductions

2. INNOVATIONS IN THE LCD INDUSTRY

BACKGROUND & DEFINITIONS

2-1. INDUSTRY BACKGROUND

Before our data

- 1970s–1990s
  - Japanese firms (Sharp, Panasonic, Sony, Hitachi, Toshiba) pioneered commercialization.
- Late 1990s
  - Samsung & LG's catch up & expansion
  - Technology transfer: Japanese → Taiwanese firms
- By 2001
  - Samsung, LG, and 4 Taiwanese firms dominated global large-area-display markets (notebook, monitor, & TV).

During our sample period (2001–2011)

- "Crystal" cartel (Oct-2001–Feb-2006)
  - Started in dot-com bubble/bust aftermath
  - Price fixing (but no investment coordination)
  - Ended when Samsung applied for "leniency" in US & EU
- Great Recession (2008:Q4–2009:Q2)
  - Samsung & LG increased market shares.
  - AUO & CMO mostly unchanged
  - CPT & HS decreased market shares.

2-2. PRODUCTION TECHNOLOGY

- Capital-intensive: Fabs cost billions of dollars.
- Knowledge-intensive: Need time & experiments to optimize new equipment
- Costs of labor & intermediate inputs: still important
- Many components & materials: sheet glass, color filters, polarizers, back lights, liquid crystal, etc.
- Any fab can produce any products (subject to: *output panel size* $\leq$ *input glass size*)

Generation	Glass size (mm)	Fab cost* (USD)
3.5	680 x 880	0.4 billion
4	730 x 920	0.4 billion
5	1,200 x 1,300	0.6 billion
5.5	1,320 x 1,500	0.6 billion
6	1,500 x 1,850	0.8 billion
7	1,950 x 2,250	1.0 billion
8	2,200 x 2,500	1.5 billion
10	2,850 x 3,250	2.5 billion

**Note*: Fab cost is for the capacity of 30,000 mother-glass sheets per month, at 1USD=100JPY.

2-3. DEFINITION OF INNOVATIONS

Product innovation

- "the introduction of a new good or of a new quality of a good" (Schumpeter 1934, p. 66)
- We separately identify:
  i. Larger products (panel size)
  ii. Other new products (resolution & backlights)

Process innovation

- "the introduction of a new method of production…
  - …which need by no means be founded upon a discovery scientifically new" (Schumpeter 1934, p. 66)
- We separately identify:
  i. Fab's technological generation ("vintage capital")
  ii. Fab's time since mass-production start ("learning by doing")
  iii. Other factors (e.g., use of one-drop-fill method, in-house production of color filters, capacity utilization, & firm's expertise)

3. DATA

SOURCES & VARIABLES

THREE DATABASES BY *DISPLAY SEARCH*:
DEEP & WIDE

1. Sales
   - Average sales price & total shipment quantities
   - Product = supplier-application-size-resolution-backlight
   - 1,081 products (or 302 if we ignore supplier identity)
   - 2001:Q1–2011:Q4 (quarterly)
2. Costs
   - Average unit cost of manufacturing, based on:
     - Raw data on input prices
     - Engineering model
   - → Can replicate costs of any product at any fab of any firm
   - …in any period 2000:Q2–2016:Q4 (quarterly)
3. Investment
   - All major firm's all fabs
   - Technological specs & capacities
   - Timing of:
     a) equipment purchase order
     b) Installation
     c) mass-production ramp
   - Average cost of investment
   - Dec-1994–Jul-2024 (monthly), including plans

4. DEMAND ESTIMATION

MODEL, ESTIMATES, & IMPLICATIONS

4-1. DEMAND MODEL FOR DIFFERENTIATED PRODUCTS

- Applications *{notebook, desktop, TV}* = separate markets
- Buyer *i*'s utility from product *j* (of size category s) in period *t*:

$$u_{ijt} = \alpha_i p_{jt} + \sum_s \beta^s \mathbb{I}\{size_j = s\} + \beta^r \ln ppi_j + \beta^b led_j + \xi_{jt} + \zeta_{ist} + (1-\rho)\varepsilon_{ijt}$$

  - Size = 11 inch, 12 inch, …, 65+ inch
  - Resolution in pixels-per-inch (PPI)
  - Backlight type = CCFL, LED (edge), & LED (direct)
- Why this specification?
  - Flexibility 1: Random coefficient on price, tied to OECD income distribution as $\alpha_i = \alpha / y_i$
  - Flexibility 2: Nests for size-bins, with ρ = importance of within-nest substitution

4-1. IDENTIFICATION & ESTIMATION (SKIPPED TODAY)

- Choice sets changed a lot.
  - Product turnover creates big variation across time (useful for identification)
- Instrumental variables (IVs)
  1. Product-level unit cost of production, c_{jt} (very rare)
  2. Dummy for existence of cartel (in 2001:Q4–2006:Q1)
  3. Number of products in each narrow category: “BLP IVs”
  4. Distance (in characteristics space) from other products: “Differentiation IVs” (Gandhi & Houde ‘23)
- Computation
  - Estimation algorithm by Berry, Levinsohn, & Pakes (‘95)
  - Python implementation in PyBLP by Conlon & Gortmaker (’20)

4-1. DEMAND ESTIMATES

Buyers care about:

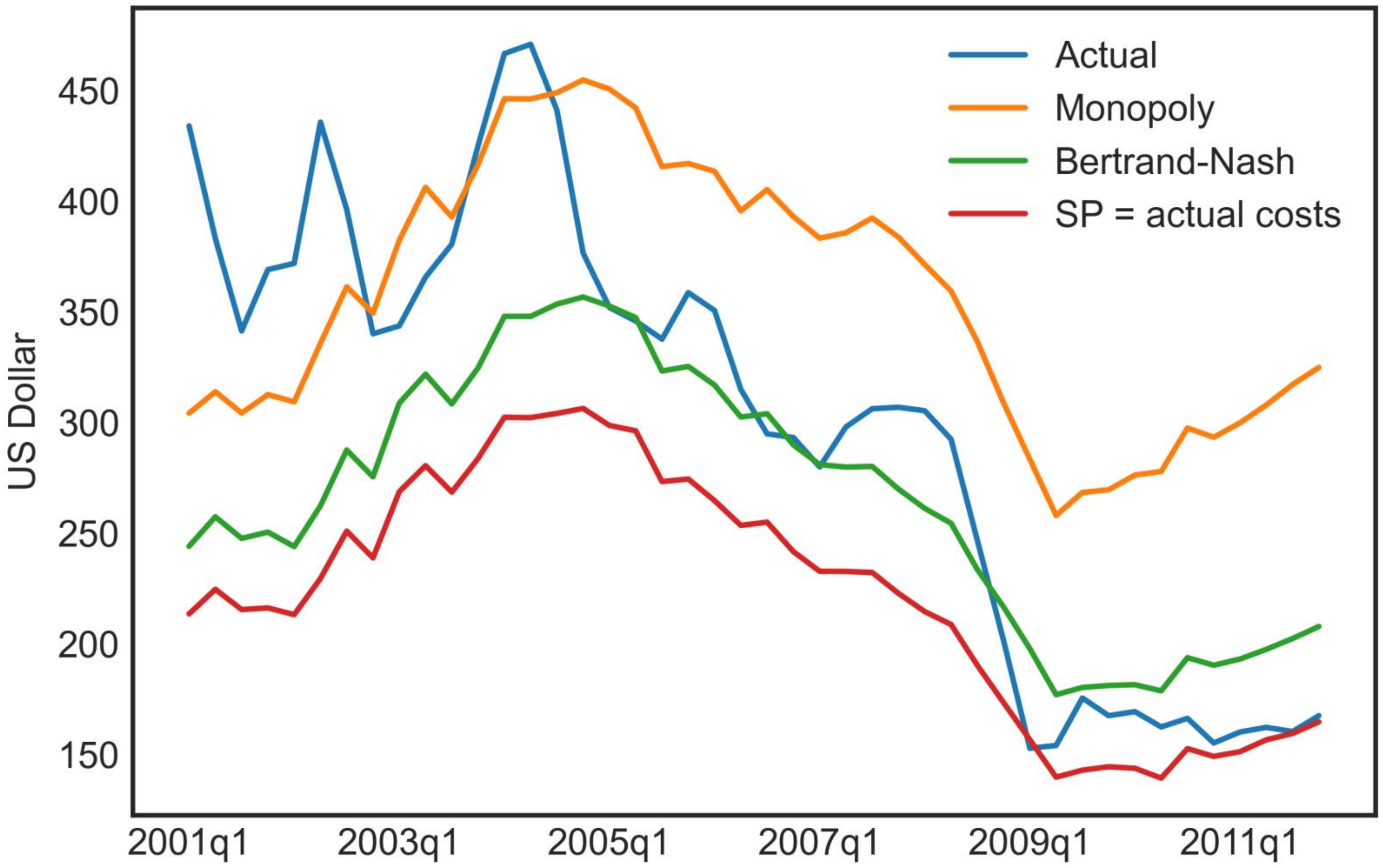
- Low prices
- Size categories
- Certain popular sizes
- Higher resolution
- Better (LED) backlights*

**Exception*: CCFL backlights seem popular in monitors.

Application	Notebook PC		Desktop monitor		TV	
Estimate	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.
Price (α)	−309.6	27.9	−155.6	5.6	−41.5	2.5
Size nests (ρ)	0.629	0.025	0.805	0.016	0.725	0.020
Size = 12" (β^{12})	1.596	0.076	–	–	–	–
Size = 13" (β^{13})	1.929	0.088	–	–	–	–
Size = 14" (β^{14})	2.906	0.095	–	–	1.892	0.185
Size = 15" (β^{15})	3.291	0.129	–	–	–	–
Size = 15.4" ($\beta^{15.4}$)	2.920	0.103	–	–	–	–
Size = 16" (β^{16})	3.006	0.114	4.872	0.080	2.821	0.156
Size = 17" (β^{17})	2.629	0.112	–	–	–	–
Size = 18" (β^{18})	0.525	0.164	6.159	0.089	1.917	0.176
Size = 20" (β^{20})	–	–	7.230	0.106	4.135	0.176
Size = 22" (β^{22})	–	–	6.753	0.110	3.979	0.194
Size = 24" (β^{24})	–	–	6.276	0.110	3.360	0.183
Size = 26" (β^{26})	–	–	–	–	4.691	0.194
Size = 27" (β^{27})	–	–	5.856	0.134	–	–
Size = 28" (β^{28})	–	–	–	–	3.822	0.266
Size = 30" (β^{30})	–	–	–	–	5.302	0.261
Size = 32" (β^{32})	–	–	–	–	6.464	0.209
Size = 40" (β^{40})	–	–	–	–	6.135	0.228
Size = 45" (β^{45})	–	–	–	–	5.997	0.233
Size = 50" (β^{50})	–	–	–	–	6.066	0.253
Size = 55" (β^{55})	–	–	–	–	6.248	0.287
Size = 60" (β^{60})	–	–	–	–	5.548	0.358
Size ≥ 65" (β^{65})	–	–	–	–	6.074	0.389
Resolution (β^r)	1.416	0.192	3.025	0.273	0.190	0.072
LED (β^b)	0.124	0.045	−0.134	0.040	0.259	0.039
Firm = Samsung	0.195	0.051	0.113	0.044	0.250	0.045
Firm = LG	0.091	0.053	0.186	0.039	0.094	0.037
Firm = CMO	−0.127	0.059	−0.161	0.041	0.072	0.044
Firm = AUO	–	–	–	–	–	–
Firm = Sharp	−0.476	0.073	−0.078	0.059	−0.067	0.042
Firm = CPT	−0.251	0.068	−0.123	0.048	−0.281	0.064
Firm = HS	−0.540	0.083	−0.062	0.055	−0.822	0.089
Firm = Others	−0.248	0.052	−0.089	0.042	−0.354	0.046
Constant	−7.580	0.582	−17.973	1.163	−10.819	0.388
Time dummies	Yes		Yes		Yes	
Own elasticity	−6.78		−9.73		−4.31	
1st-stage R^2: price	0.941		0.893		0.920	
1st-stage R^2: share	0.378		0.370		0.453	
Number of obs.	4,140		3,374		3,582	

4-2. MARKUP IMPLICATIONS

1. Actual price ≈ monopoly in 2001–2004
2. Actual price ≈ Bertrand in 2005–2008
3. Actual price ≈ marginal costs in Great Recession

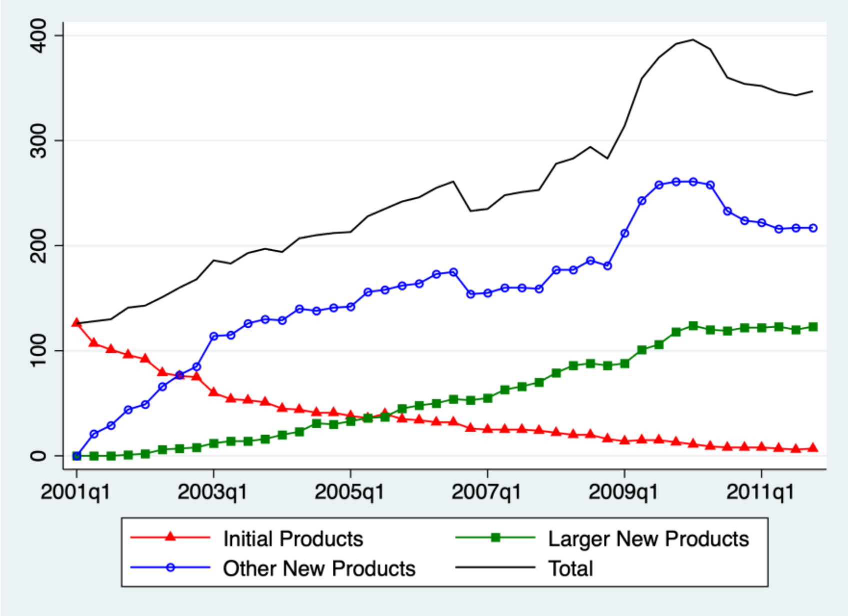


5. WELFARE GAINS FROM INNOVATIONS

PRODUCT & PROCESS INNOVATIONS; NEW-GENERATION FABS = BUNDLE OF INNOVATIONS

5-1. PRODUCT INNOVATION:
NEW PRODUCTS

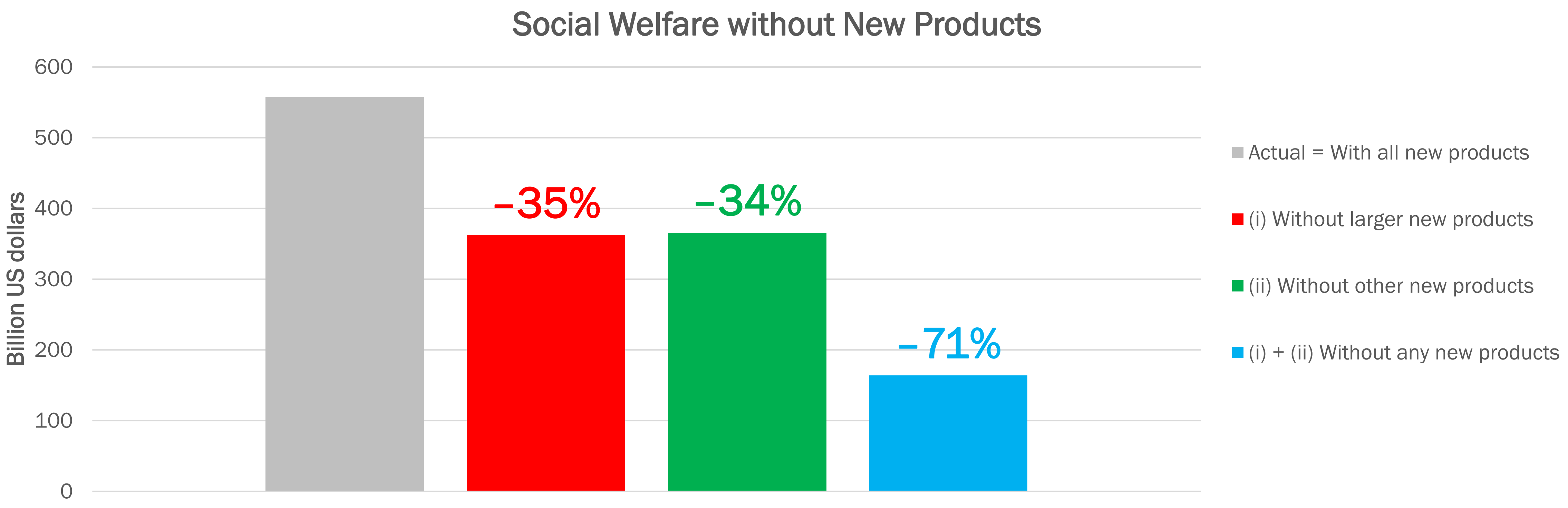
Number of products



Three groups

- Initial products in 2001:Q1
  - Largest = 15.7'' notebooks; 24'' monitors; 28'' TVs
- Larger new products
  - 16''–20'' notebooks
  - 25''–31.5'' monitors
  - 29''–80'' TVs
- Other new products
  - New size-resolution combinations
  - New (LED) backlights

5-1. PRODUCT INNOVATION:
WELFARE IMPACT



5-2. PROCESS INNOVATION:
DETERMINANTS OF MANUFACTURING COST

- Regression to summarize engineering cost model
- Cost of manufacturing product *j* in fab *k* in period *t*:

$$\ln c_{jkt} = \underbrace{\sum_g \theta^g \mathbb{1}\{gen_k = g\} + \sum_a \theta^a \mathbb{1}\{age_{kt} = a\} + \theta^{odf} odf_k + \theta^{cf} cf_{f(k)t}}_{\text{process innovations}}$$

$$+ \sum_c \theta^c \mathbb{1}\{capa_{kt} = c\} + \underbrace{\tilde{\mu}_t + \tilde{\gamma}_{f(k)} + \tilde{\nu}_j}_{\text{time, firm, \& product dummies}} + \eta_{jkt}$$

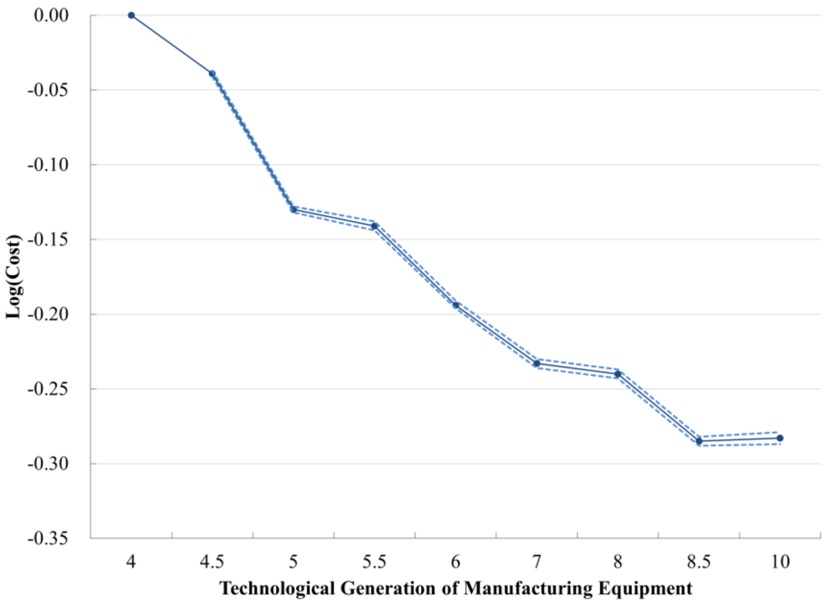
  - Fab's generation = vintage capital
  - Fab's age = experience (learning by doing)
  - One-drop-fill (ODF) method = a new process from 5G

Specification	(1)		(2)		(3)		(4)	
Estimate	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.
A. Fab specs								
Tech. gen.	−0.045	(0.000)	−0.208	(0.002)	−0.178	(0.002)	–	(–)
Tech. gen. squared	–	(–)	0.012	(0.000)	0.010	(0.000)	–	(–)
Fab age	−0.003	(0.000)	−0.015	(0.000)	−0.015	(0.000)	–	(–)
Fab age squared	–	(–)	0.000	(0.000)	0.000	(0.000)	–	(–)
ODF method (θ^{odf})	−0.102	(0.001)	−0.005	(0.001)	−0.011	(0.001)	−0.006	(0.001)
In-house CF (θ^{cf})	−0.022	(0.001)	0.011	(0.001)	−0.011	(0.001)	0.003	(0.001)
Capa. util.	−0.213	(0.004)	−0.244	(0.032)	−1.171	(0.037)	–	(–)
Capa. util. sqared	–	(–)	0.038	(0.021)	0.596	(0.025)	–	(–)
B. Firm specs								
Tier-1	−0.194	(0.003)	−0.105	(0.003)	−0.108	(0.003)	−0.085	(0.003)
Korea	−0.107	(0.001)	−0.111	(0.001)	−0.111	(0.001)	–	(–)
Taiwan	−0.286	(0.003)	−0.192	(0.003)	−0.196	(0.003)	–	(–)
C. Product specs								
Surface area	0.925	(0.001)	0.932	(0.001)	0.932	(0.001)	–	(–)
Monitor	−0.106	(0.001)	−0.109	(0.001)	−0.108	(0.001)	–	(–)
TV	0.086	(0.002)	0.077	(0.002)	0.074	(0.002)	–	(–)
LED (edge)	0.060	(0.001)	0.064	(0.001)	0.064	(0.001)	–	(–)
LED (direct)	−0.132	(0.001)	−0.127	(0.001)	−0.126	(0.001)	–	(–)
D. Time and others								
Time	−0.030	(0.000)	−0.092	(0.002)	–	(–)	–	(–)
Time squared	–	(–)	0.000	(0.000)	–	(–)	–	(–)
Constant	13.533	(0.013)	20.133	(0.153)	9.193	(0.027)	5.175	(0.018)
Tech. gen. dummy (θ^g)	No		No		No		Yes	
Fab age dummy (θ^a)	No		No		No		Yes	
Capa. util. dummy (θ^c)	No		No		No		Yes	
Firm dummy ($\tilde{\gamma}_f$)	No		No		No		Yes	
Product dummy ($\tilde{\nu}_j$)	No		No		No		Yes	
Time dummy ($\tilde{\mu}_t$)	No		No		Yes		Yes	
Number of obs.	341,216		341,216		341,216		341,216	
R^2	0.963		0.966		0.969		0.984	
Adjusted R^2	0.963		0.966		0.969		0.984	

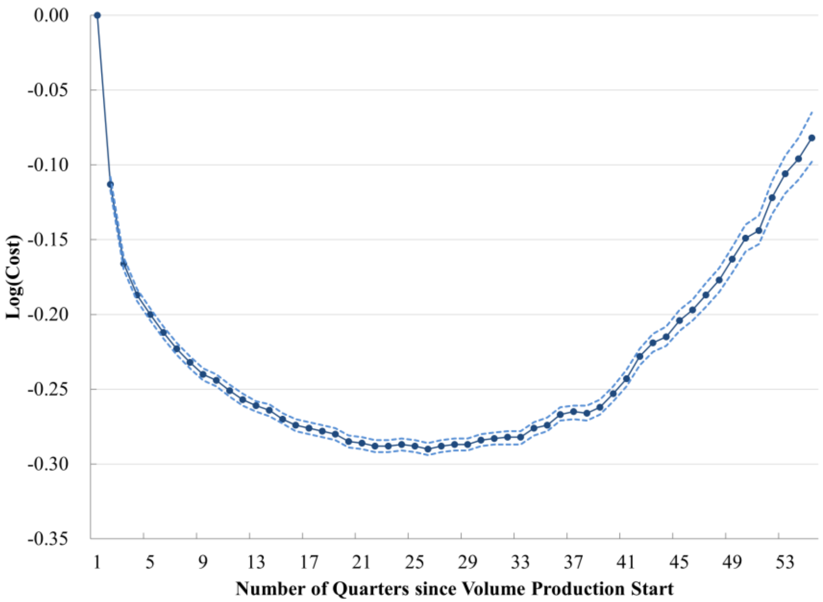
Note: The dependent variable is the natural logarithm of the unit cash cost of producing an LCD panel. Standard errors are in parentheses. See the main text for the explanation of the regressors. All estimates are based on the ordinary-least-squares (OLS) regressions and meant to summarize the engineering cost estimates underlying the data.

5-2. PROCESS INNOVATION:
HOW UNIT COST DECLINES WITH VINTAGE & EXPERIENCE

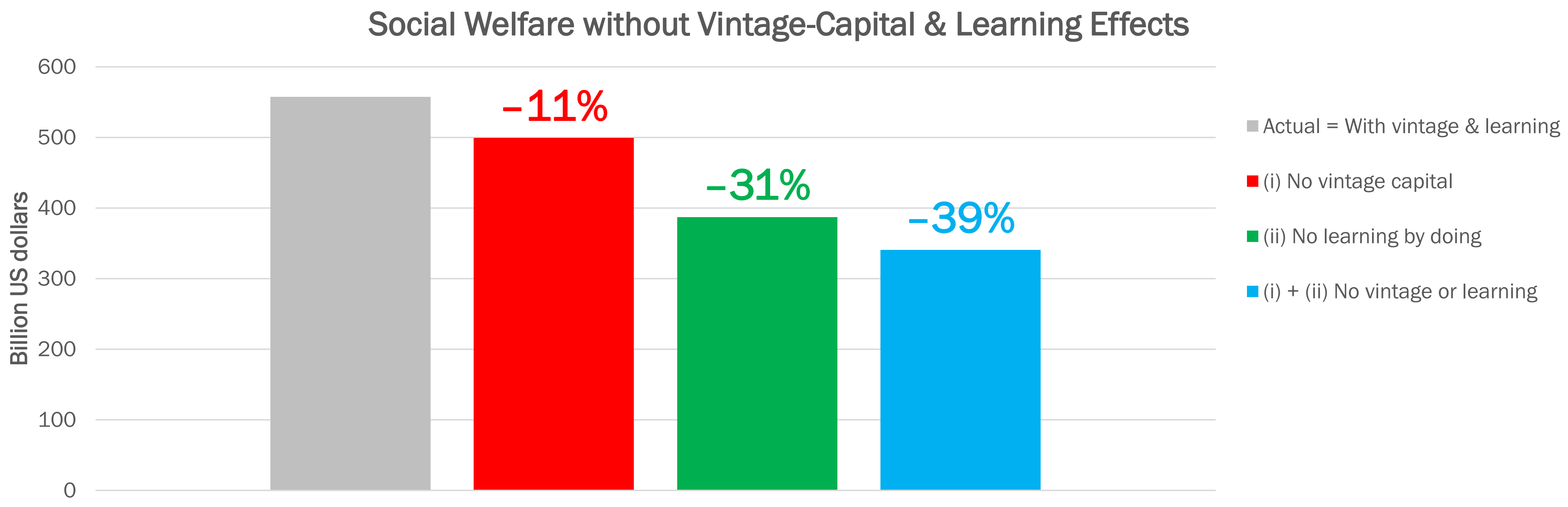
Capital vintage



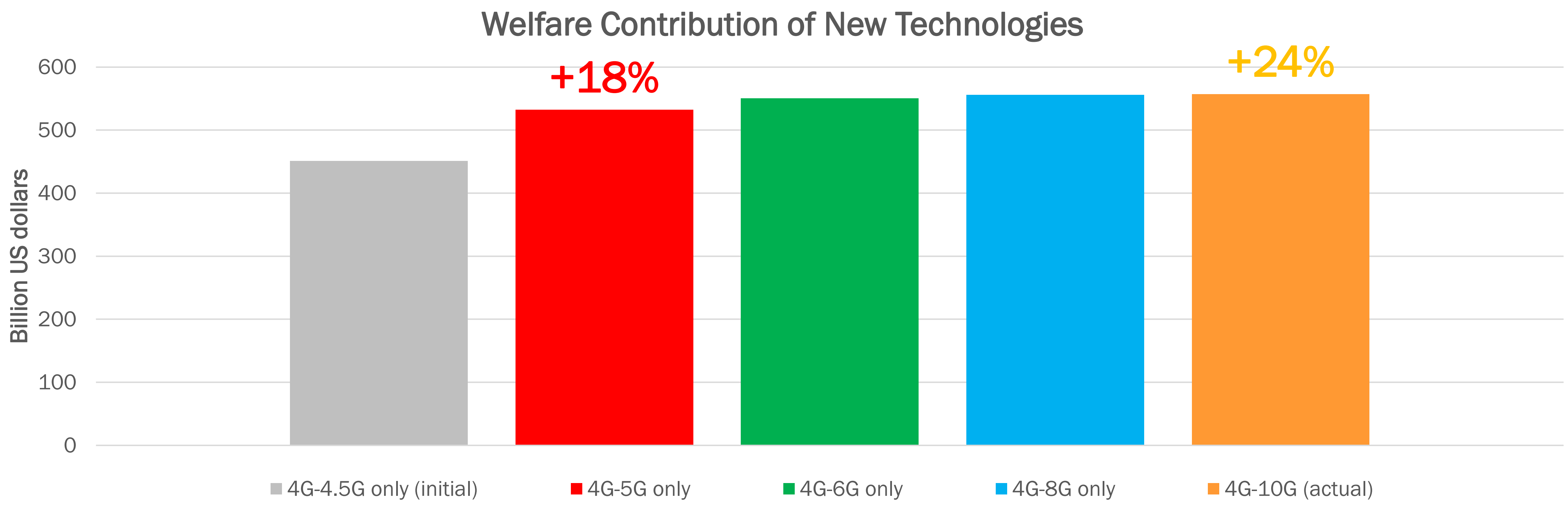
Experience (age of fab)



5-2. PROCESS INNOVATION:
WELFARE IMPACT



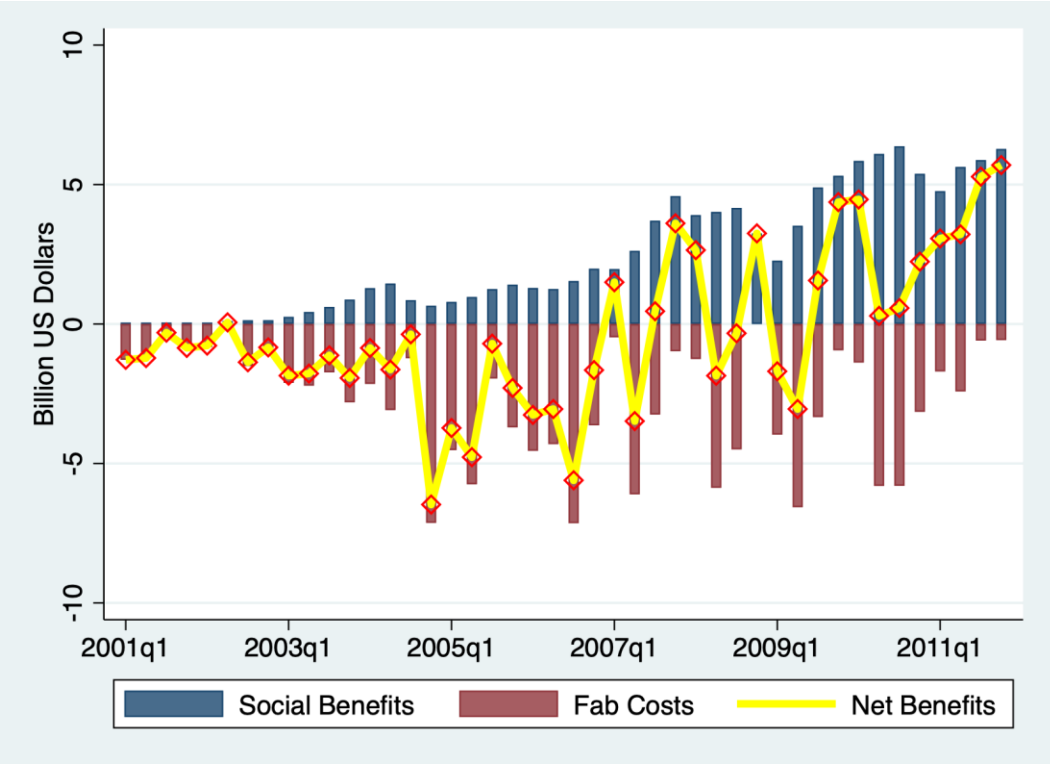
5-3. NEW-GEN FABS = LARGER NEW PRODUCTS + VINTAGE CAPITAL



6. SOCIAL & PRIVATE RETURNS ON INVESTMENT

WERE THOSE FAB INVESTMENTS WORTH IT?

6-1. AGGREGATE RETURNS ON FAB INVESTMENTS (1 OF 2):
SOCIAL BENEFITS & COSTS



Note: Period-by-period comparison, without any time-discounting.

6-1. AGGREGATE RETURNS ON FAB INVESTMENTS (2 OF 2):
SOCIAL & INDUSTRY R.O.I.

Annual discount rate	1%	2.5%	5%	10%
1. Change in consumer surplus	1,646	594	250	89
2. Change in producer surplus	477	174	75	27
3. Change in social welfare (= 1 + 2)	2,123	768	325	116
4. Fab investment cost	117	107	92	69
5. Change in net social value (= 3 – 4)	**2,006**	**661**	**233**	**47**
6. Change in net producer value (= 2 – 4)	**360**	**67**	**–18**	**–41**

Note: All numbers are discounted present values in billion US dollars as of 2001:Q1. The industry's internal rate of return (IRR = break-even discount rate) is 4.05%.

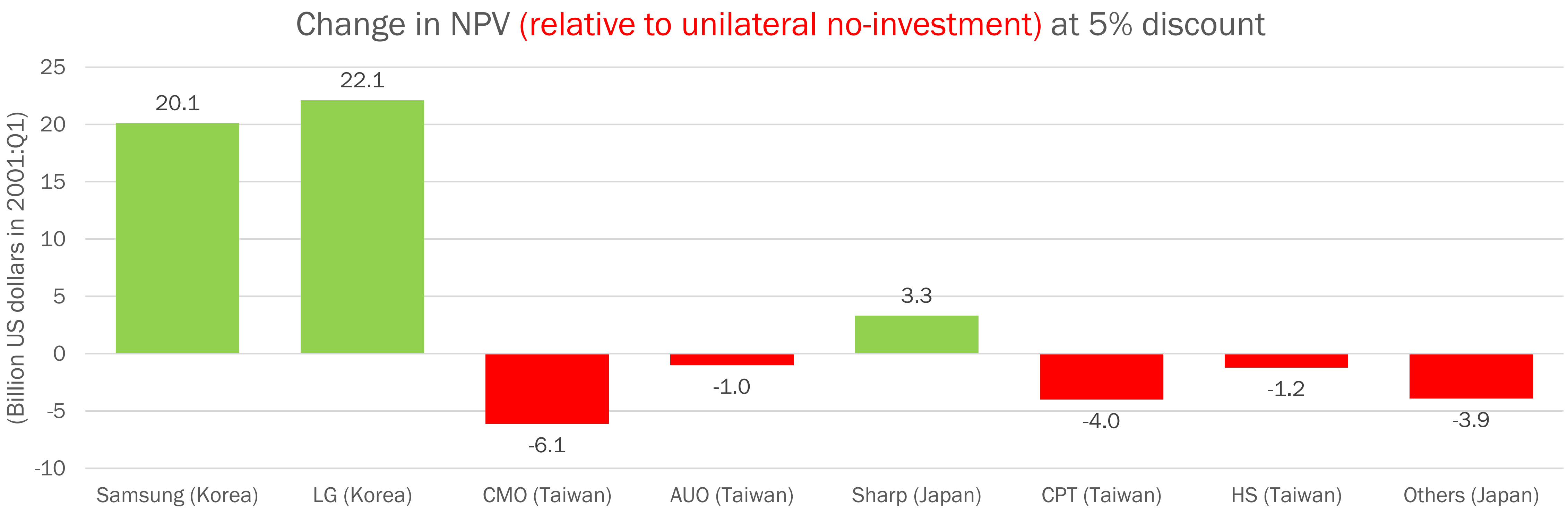
6-2. COMPETITIVE PRESSURE UNDER OLIGOPOLY (1 OF 2)

- **Question:** Why did firms invest in new fabs despite low (realized) returns?

- **Answer:** No investment, no profit.

- To measure firm *f*'s strategic incentive, compare the Discounted Present Values (DPVs) of:
  - A. *Actual* profits with investments while others invest $\pi_f(1,1)$
  - B. *Counterfactual* profits without investments while others invest $\pi_f(0,1)$
  - *A – B*: Difference in Net Present Value (NPV) $\Delta NPV_f \equiv DPV\left[\pi_f(1,1) - \pi_f(0,1)\right]$

6-2. COMPETITIVE PRESSURE UNDER OLIGOPOLY (2 OF 2)



- Samsung & LG had big, positive incentives; others were "on the fence."

7. MARKET STRUCTURE & INCENTIVE TO INNOVATE

DO MERGERS INCREASE INNOVATION INCENTIVES?

7-1. SEVEN-TO-SIX MERGERS (1 OF 2)

- **Question:** Did "too much competition" reduce innovation incentives?

- **Answer:** Yes & no.
  - …based on the simulation of ***all possible seven-to-six mergers***

- To measure merger's impact on industry-wide incentive to innovate, compare:

  A. *Actual* Sum of Individual Incentives (SII) with 7 firms $SII(7) = \sum_f \Delta NPV_f(N = 7)$

  B. *Counterfactual* SII with post-merger 6 firms $SII(6) = \sum_f \Delta NPV_f(N = 6)$

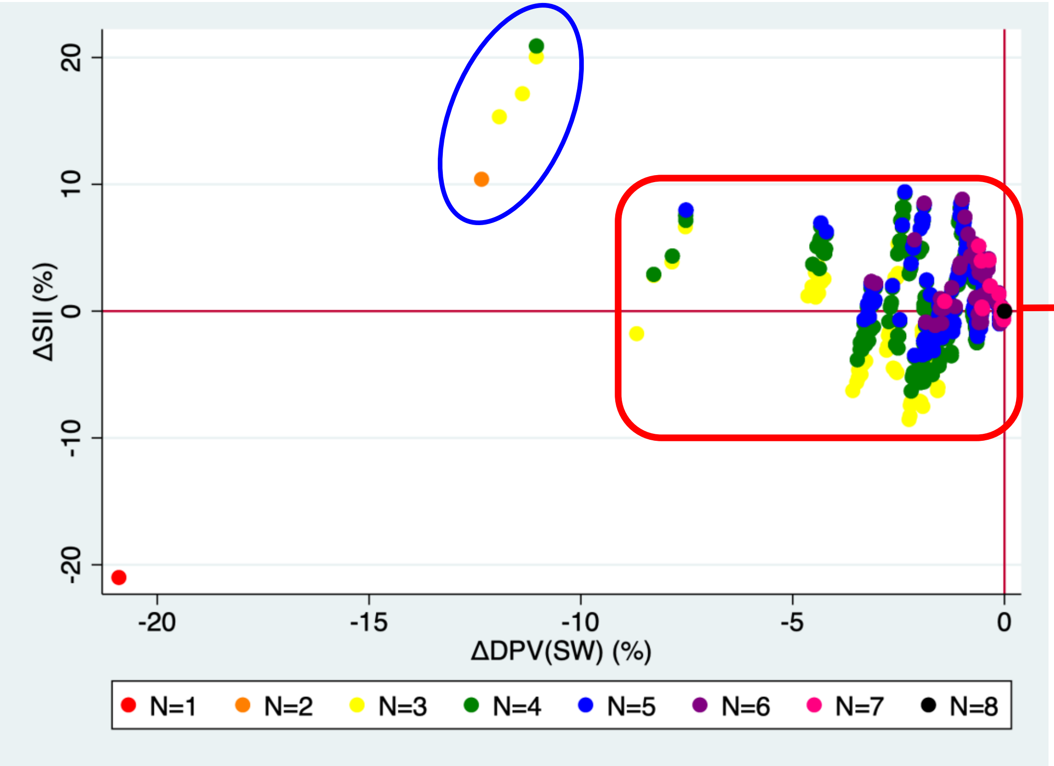
  B – A: Change in innovation incentives $\Delta SII = SII(6) - SII(7)$

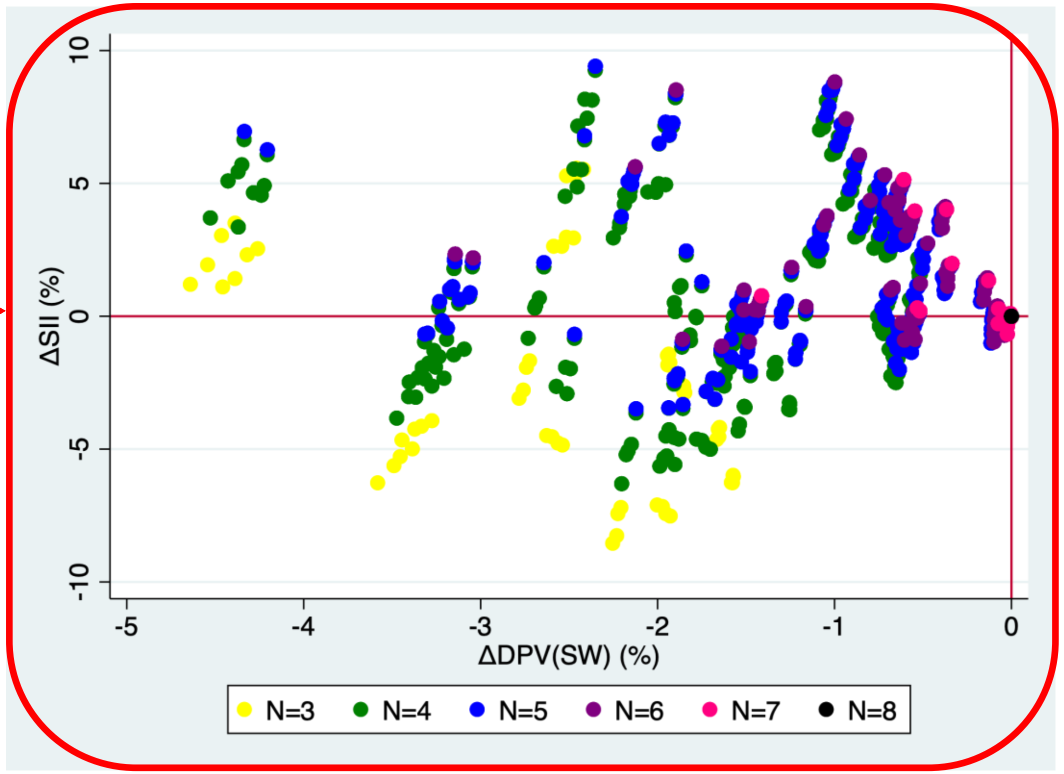
7-1. SEVEN-TO-SIX MERGERS (2 OF 2)

Merger	Acquirer	Target	Welfare effect $\Delta DPV(SW)$	(% change)	Incentive effect ΔSII	(% change)
1	Samsung	LG	–17.7 billion USD	(–1.4%)	+0.2 billion USD	(+0.8%)
2	LG	AUO	–7.6 billion USD	(–0.6%)	+1.5 billion USD	(+5.1%)
3	LG	CMO	–6.8 billion USD	(–0.5%)	+1.2 billion USD	(+4.0%)
4	Samsung	CMO	–6.7 billion USD	(–0.5%)	+0.1 billion USD	(+0.3%)
…						
9	CMO	Sharp	–0.9 billion USD	(–0.1%)	–0.1 billion USD	(–0.3%)
10	AUO	Sharp	–0.9 billion USD	(–0.1%)	+0.1 billion USD	(+0.3%)
11	LG	CPT	–0.3 billion USD	(–0.0%)	–0.2 billion USD	(–0.7%)
12	Samsung	CPT	–0.3 billion USD	(–0.0%)	–0.1 billion USD	(–0.4%)

- All mergers reduce (static) welfare.
- 14 (out of 21) mergers increase innovation incentives, which *might* improve long-run welfare.
- In the remaining 7 cases, $\Delta SII < 0$.

7-2. ALL OTHER MERGERS (1 OF 2)





- *Some* mergers are good for innovation incentives ($\Delta SII > 0$ on Y-axis).
- But effects are *very* merger-specific, and mostly negative ($\Delta SII < 0$) when $N \leq 5$.

7-2. ALL OTHER MERGERS (2 OF 2)

Merger from/to	Possible Mergers	Welfare effect, $\Delta DPV(SW)$		Incentive effect, ΔSII			
		Mean	Std. dev.	Mean	Median	Std. dev.	Frac < 0
7 to 6	21	–0.2%	0.3%	+0.8%	+0.1%	1.6%	0.33
6 to 5	315	–0.3%	0.5%	+0.7%	+0.0%	1.7%	0.48
5 to 4	1,400	–0.5%	0.8%	+0.4%	–0.1%	2.1%	0.59
4 to 3	2,100	–1.0%	1.3%	–0.4%	–0.5%	3.2%	0.67
3 to 2	903	–2.3%	2.6%	–1.3%	–2.7%	6.4%	0.74
2 to 1	63	–9.2%	2.4%	+12.1%	+13.6%	6.2%	0.05
No Others	1	–9.8%	N/A	–28.4%	–28.4%	N/A	1.00

- Effects are *increasingly* more merger-specific as industry consolidates.
- The *majority* of mergers reduce innovation incentives ($\Delta SII < 0$) when $N \leq 5$.
- The "2 to 1" case is an outlier (orange dot on previous page).

CONCLUSION: SUMMARY OF FINDINGS

1. Product & process innovations: 71% and 39% of total welfare
2. High social return, low private returns
3. Some mergers increase innovation, but mostly negative effects when $N \leq 5$
4. Patterns robust to almost any parameter values; mergers are pro-innovation only under *very low* $|\alpha|$

- This paper: emphasis on data, with minimal static model
  - ✓ Cannot solve *all* problems
  - ✓ Igami, Kaji, Qiu, Scheidegger, & Sugaya (202X): dynamics with endo. collusion & innovation