Mergers and Innovation: The Case of Hard Disk Drives

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Motivation

- Report for DG COMP: "Feasibility study on the microeconomic impact of enforcement of competition policies on innovation"
- Large number of papers on the relationship between market structure and innovation, mergers and innovation - but most are aggregate studies.
- We look at a single market, hard disk drives, in great detail.
  - Seagate/Samsung, Western Digital/Hitachi (2.5in) and Toshiba/Hitachi (3.5in) mergers (5 to 3) in 2012.
  - Question: how did the mergers affect innovation at Seagate, Western Digital, and Toshiba?

What we learned from our literature review

- On the empirical side, there have been "only a few studies specifically address(ing) the effects of mergers on innovation" (Gilbert 2019) - stark contrast between the enormous number of price impact studies of mergers.
- Within the theoretical literature, there are arguments both ways on whether, in general, mergers encourage or discourage innovation, and the same is true for the aggregate multi-merger empirical studies.
- A more important lesson to draw from the theory is that mergers are heterogeneous in numerous dimensions, which could explain the mixed results. So we need individual case studies.

What we learned from our literature review

- It is potentially misleading to equate "innovation" simplistically with either R&D or patents. R&D is an input measure which, in itself, tells us little about the efficacy of research.
- For patents the distinction between inputs and outputs is less clear-cut – can a patent be immediately translatable into a commercially viable innovation (see also defensive patenting)
- This suggests that a holistic approach is called for. We draw together different proxies for innovation which allow us to disentangle the quantity of innovative effort (R&D and patents) from its efficacy and productivity.

Main contributions

- Empirical literature dominated by studies on mergers and prices, while this is a rare example of how innovation changed following merger.
- Most previous applied studies have taken the industry as the unit of observation; this paper, on the other hand, drills down to the firm level (to recover asymmetries).
- We adopt a holistic view of innovation, employing four different measures: R&D, patents, the number of new models marketed, and their unit prices. This allows us to distinguish the magnitude of the merging parties' innovative efforts from the productivity of those efforts.

THE MARKET AND REGULATORY APPROVAL

The storage market

- Two main data storage technologies: Hard Disk Drives (HDD), and Flash memory-based storage systems.
- HDDs use one or more rotating disks with magnetic surfaces (media) to store and allow access to data,
- Flash memory uses integrated circuit assemblies to store data, which records, stores and retrieves digital data without any moving parts. Two types of Flash memory are solid state drives (SSD) and USB Flash drives.
    - SSDs are built on semiconductor memory arranged as a disk instead of magnetic or optical storage support.

The storage market

- The main advantages of SSDs compared to HDDs: speed, lower power consumption, increased resistance to shock, and reduced noise and heat generation.
- A major disadvantage of SSDs is their price,
- HDDs remain the primary technology for archiving, while SSDs are mainly employed in portable devices (laptops, smartphones, tablets).
- The increase in storage demand is from the growth in data archives and cloud storage, which rely, to a large extent, on HDDs.
- Storage in mobile devices, using flash based technologies, remains only a tiny fraction of all storage capacity, despite its wide dissemination.

Flash/SSD - our main control group

When looking at measures of innovation input (R&D and patents), we compare technologies (HDD vs flash):

- Flash is used a number of applications (only one of these is SSD).
- Implicit assumption that an innovation in flash will have (some) impact on SSD.

When looking at measures of innovation output, our focus shifts to the physical product (SSD)

Flash/SSD - our main control group

Are SSD and HDD in different product markets?

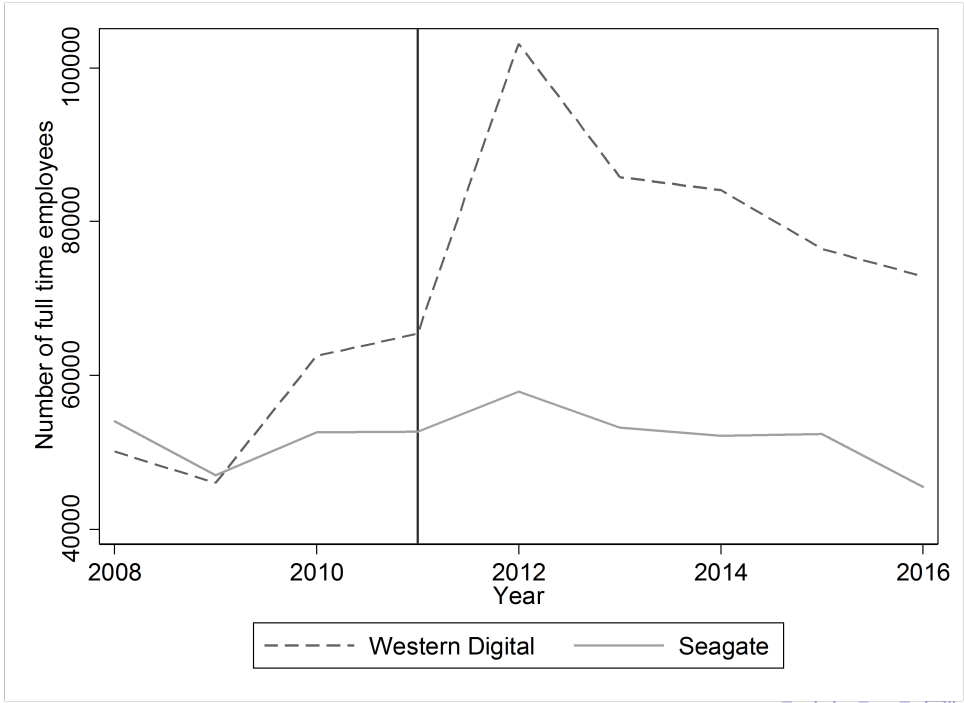
- EC case report says yes (at the time of the merger).
- Industry opinion says yes:
  - In applications where unit price dictates purchasing behaviour HDD dominates (e.g. data servers - cold and archive data, or surveillance data).
  - In other areas (mobile and local user created data) SSD is dominant.
- In each of these areas, competition does not appear very strong between the technologies, they are more likely to be complements than substitutes (e.g. data archives, SSD is used largely as a complement in caching and restoring to speed up data transfers). SSDs also speed up access to storage metadata or are used to boot storage pods.
- Hybrid drives

Regulatory approval - Seagate/Samsung

- Seagate/Samsung: unconditionally approved in every jurisdiction, except China (MOFCOM), where subject to conditions.
- WD/Hitachi merger approved subject to the divestiture of 3.5" desktop hard disk drives to Toshiba. MOFCOM restrictions crippled WD's chances of an efficient operation.
- Toshiba/Hitachi (3.5in): unconditionally approved everywhere.
- MOFCOM required the parties to hold R&D activities separate post-merger, and to not reduce them below a specified level.

Regulatory approval - Seagate/Samsung

Restrictions were much more stringent on WD than on Seagate. WD was practically forced to operate with inefficiently duplicated production, marketing and sales operations for WD and HGST. This circumvented any possibility of increased efficiency.



DATA

Outcome variables

We look at four measures of innovation:

- R&D intensity
- Patent activity
- Number of new models
- Unit price of storage

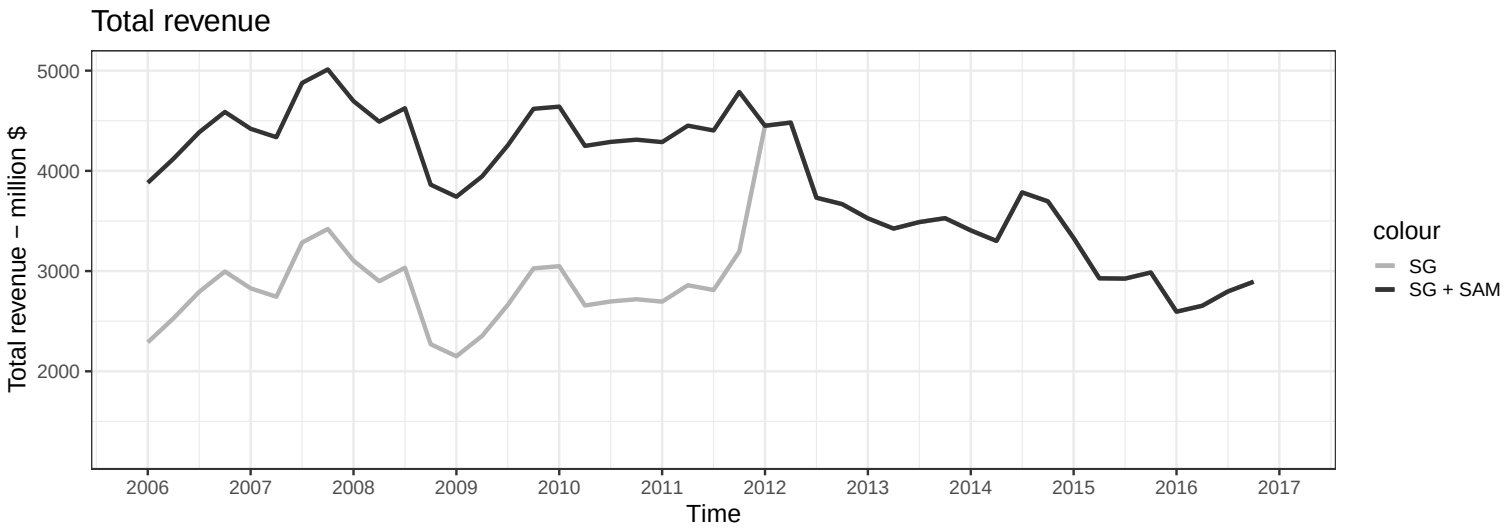
For all measures we concentrate on quarterly data coverage for (Q1 2007 - Q4 2016).

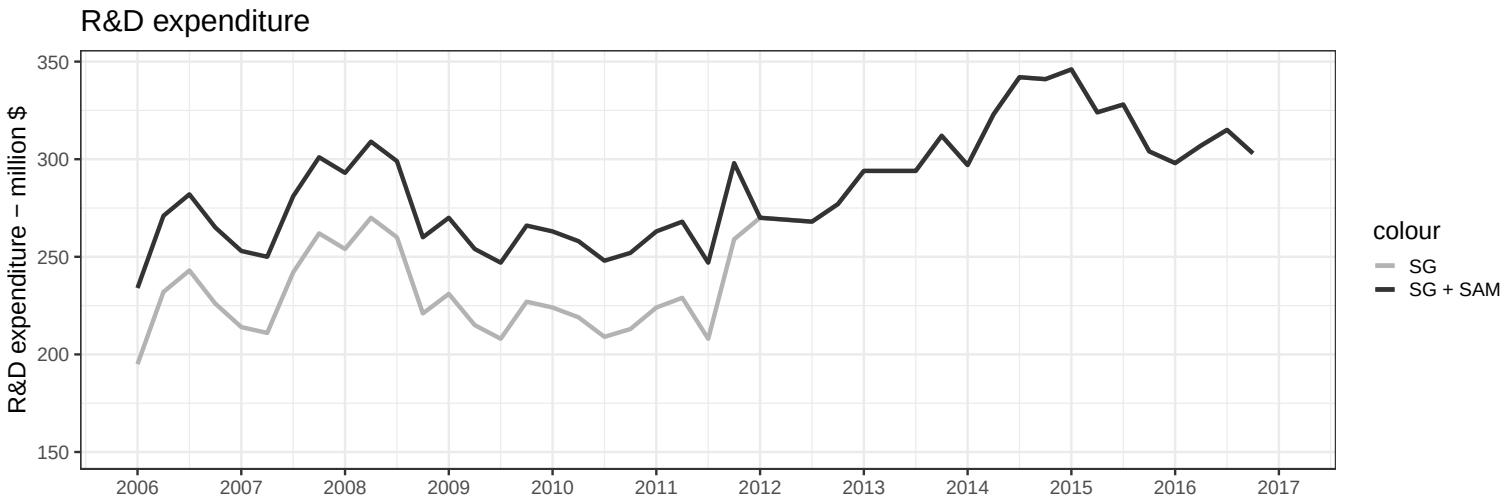
Outcome variable - R&D intensity

Ratio of R&D expenditure to total revenue.

- This is from firms' financial statements, as downloaded from S&P's Capital IQ database.
- Two methodological issues.
  - Elements of the financial statement of the acquired company are added to the corresponding elements of the financial statement of the acquiring company. How we deal with this?
  - Difficult (if possible at all) to acquire data specifically for the relevant segments or products of the analysed firms if they are diversified (Seagate and WD were fine, Toshiba not)

Outcome variable - R&D intensity





Outcome variable - Patents

- We extracted all patent data for each technology (HDD, Flash), and grouped the data by firms/quarters.
- 8433 Flash patents (4815 in the relevant period), 5863 (2605) HDD patents.
- Data scraped from USPTO, using Patentsview API (different from older version).
- The effective date of each patent application refers to the quarter when a first application is registered.

Outcome variable - Number of new models

We scraped various information on HDD and SSD products from Amazon, this included:

- **Date first marketed on Amazon:** There is some grouping in the way firms market new HDDs and SSDs. For example, 17 different Intel SSDs appeared on Amazon on 27 March 2016. (more than 2/3 of all drives in our sample were marketed on unique days, and most groupings happened in 2s).
- Using this date we calculated the firm/quarter number of new model.

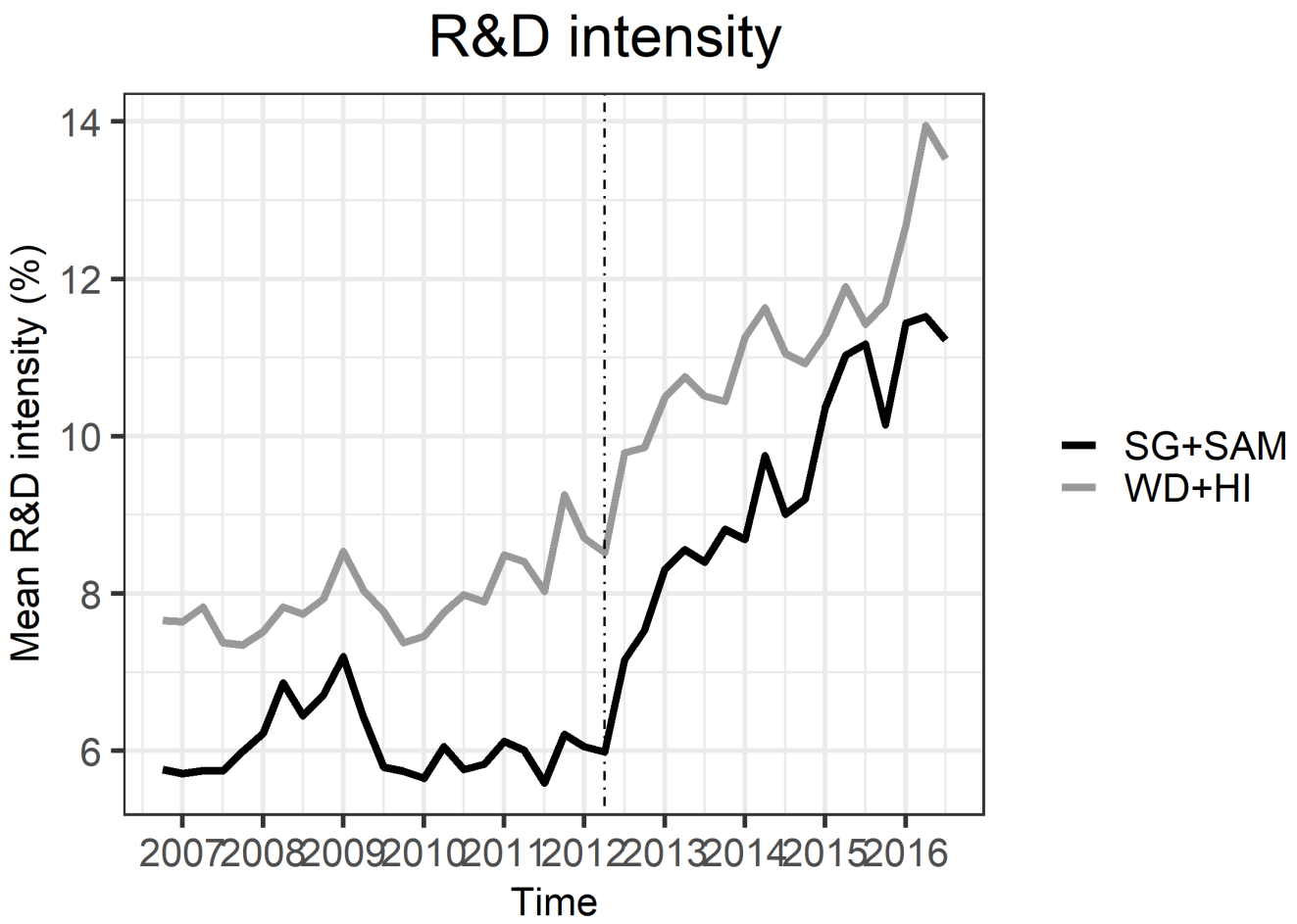
Outcome variable - Unit price (USD/Gb)

For this we needed:

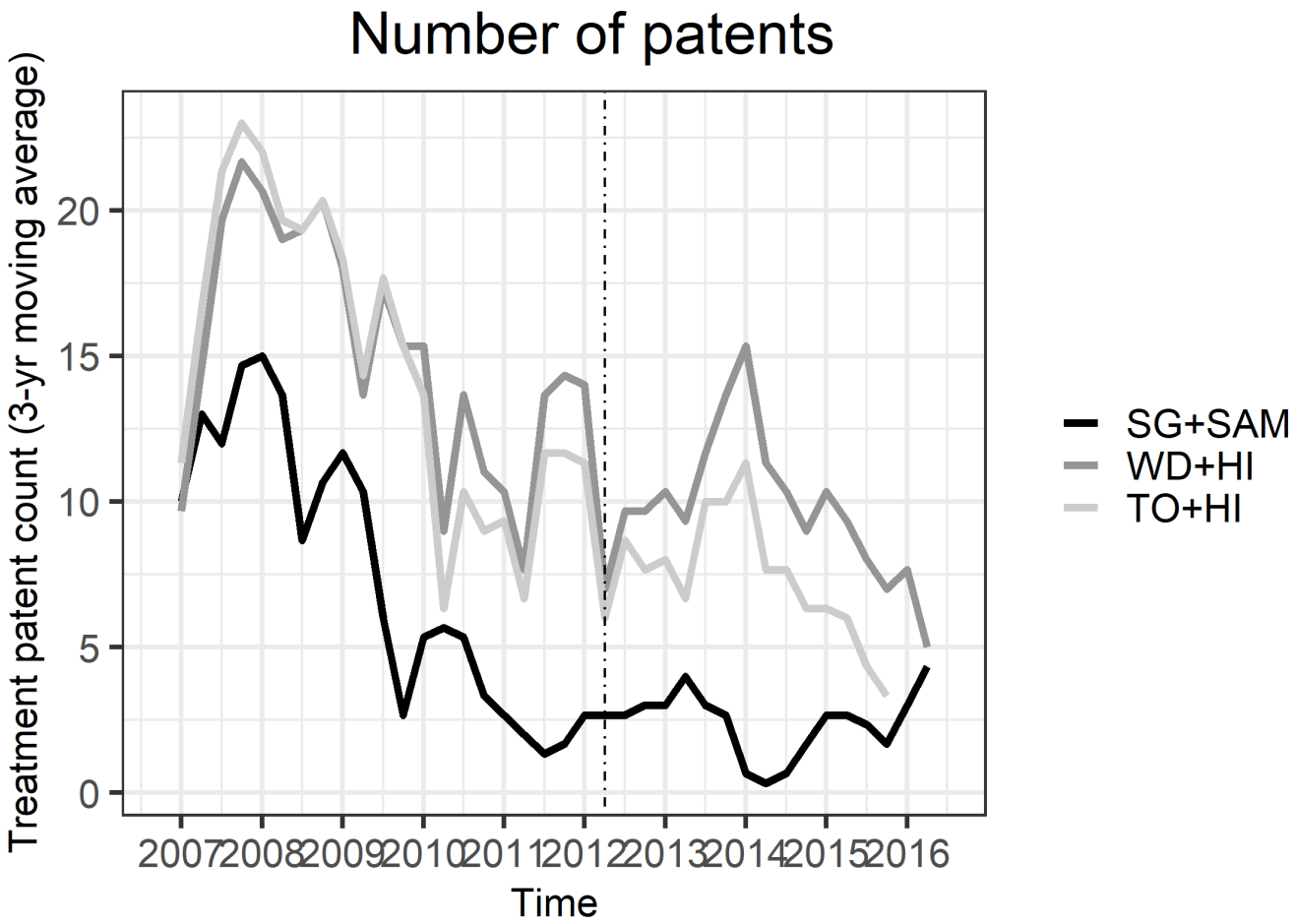
- **Storage capacity:** Ideally, one would have looked at areal density. However using retail data we had limited access to technological details and could only measure formatted capacity (expressed in Gb). This also allowed comparisons with SSD. Capacity alone does not give an unambiguous picture of innovation because newer products do not necessarily mean larger capacity.
- **Retail price:** Retail price of HDD.

DESCRIPTIVE FIGURES

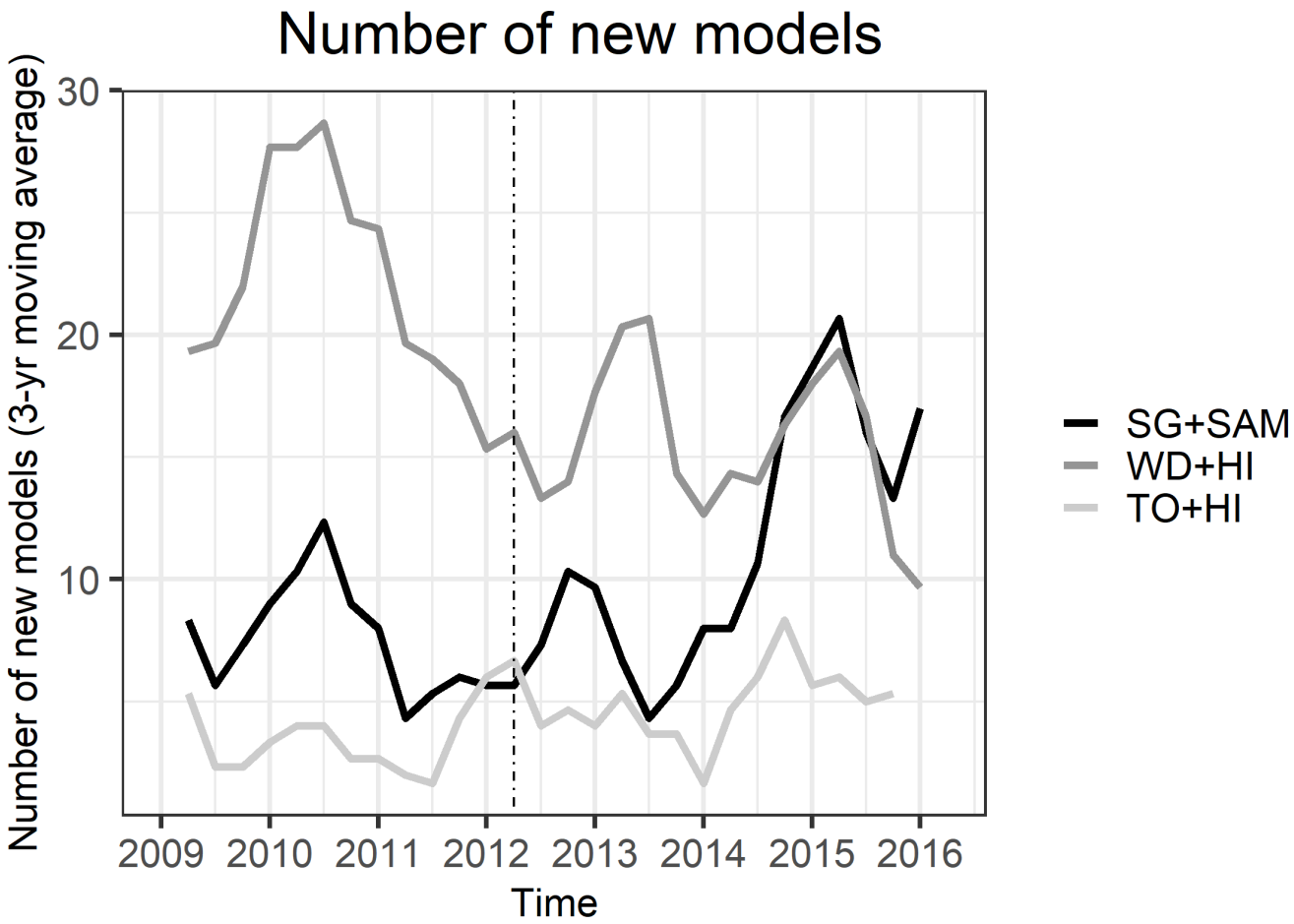
Descriptive figures - R&D intensity



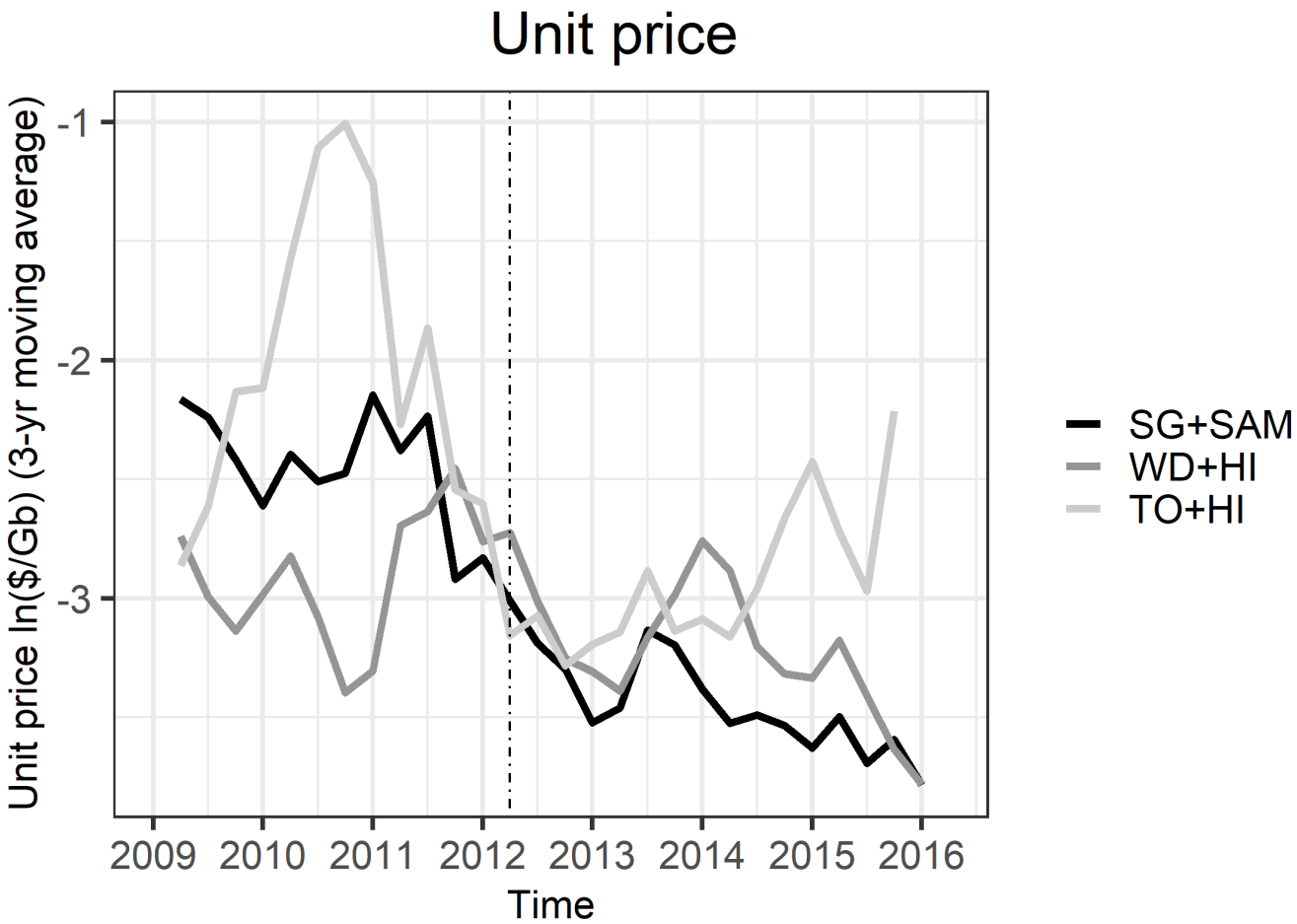
Descriptive figures - Patent count



Descriptive figures - New models



Descriptive figures - Unit price



Econometrics

ECONOMETRIC METHODOLOGY

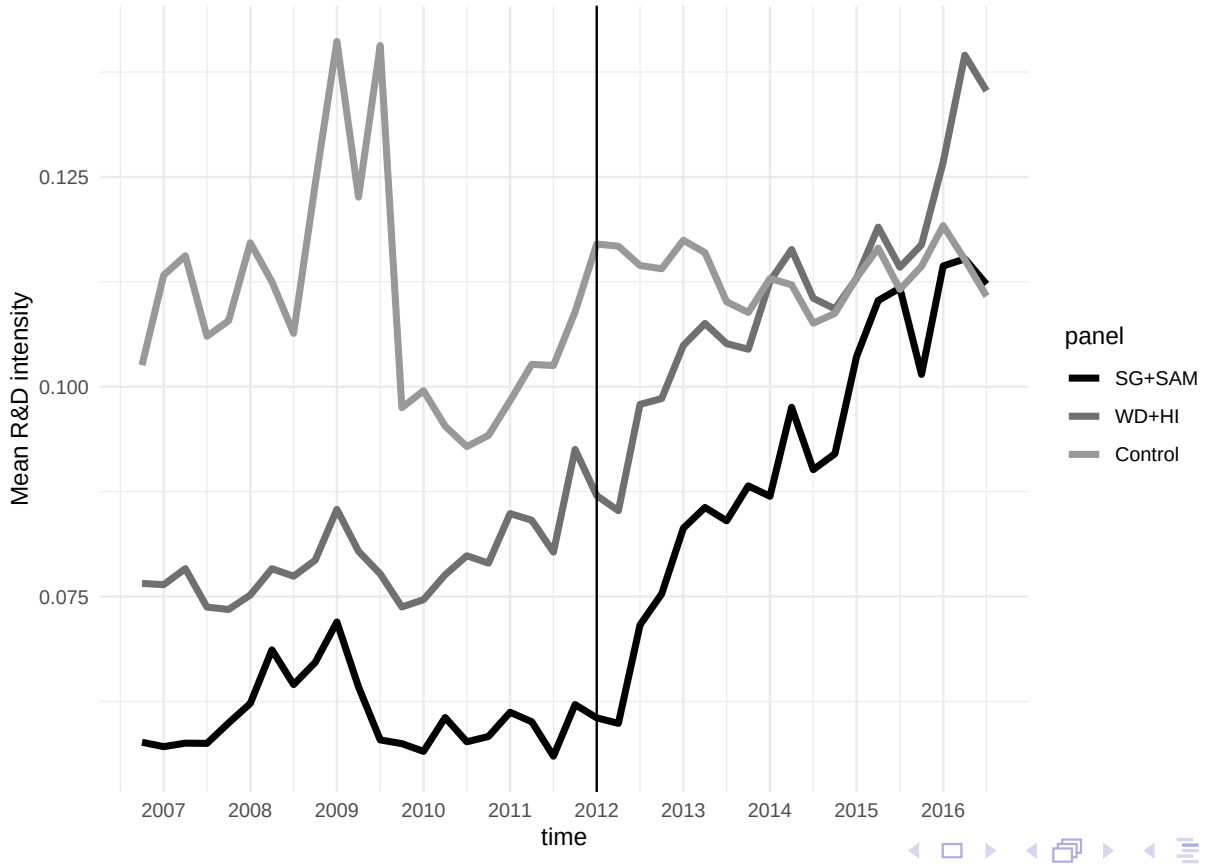
How can we establish a causal relationship?

How much can these changes be attributed to the consolidation?

- Linear two-way fixed effect model is one of the most commonly used methods.
- Key assumption: large set of unobserved unit- and time-invariant confounders are controlled for (parallel trends pre-merger).
- (another assumption is independence - later)
- But what if the unconfoundedness assumption is violated?

Absence of time-varying confounders?

Figure: R&D intensity for Seagate, WD, and the control



Estimating the counterfactual: Matrix completion

- We need to reconstruct the untreated (no merger) state of the world.
- Matrix completion (Athey et al.,2018) can be used to estimate this unobserved world.
- The idea is to treat the unobserved (untreated) states of the treated units as missing and use a penalised matrix decomposition to reconstruct these from the rest of the dataset.

Matrix completion

- What is matrix completion? The Netflix Prize.

	Moonlight	Inception	Parasite	Mad Max	The Avengers
Ethel	5	.	.	3	.
Lewis	.	3	2	.	5
Ernest	.	.	4	5	.
Albert	4	.	.	.	1

- Get principal components to calculate missing ratings.

Matrix completion

- Imagine the same matrix as dense

	Moonlight	Inception	Parasite	Mad Max	The Avengers
Ethel	5	4	5	3	1
Lewis	2	3	2	4	5
Ernest	3	4	4	5	1
Albert	4	4	5	2	1

- PCA to get film and viewer features. SVD to generate the film/viewer factors.

Matrix completion

Causal inference here seen as the task of completing a $N \times T$ matrix with missing entries, where the missing entries are associated to the treatment, $D_{it} = 1$. Example of outcome matrix:

$$\underset{N \times T}{Y} = \begin{pmatrix} \checkmark & \checkmark & \checkmark & \checkmark & \cdots & \checkmark \\ \checkmark & \checkmark & \checkmark & \checkmark & \cdots & \checkmark \\ \checkmark & \checkmark & \checkmark & \checkmark & \cdots & \checkmark \\ \checkmark & \checkmark & \checkmark & ? & \cdots & ? \\ \checkmark & \checkmark & \checkmark & ? & \cdots & ? \\ \vdots & \vdots & \vdots & ? & \ddots & ? \\ \checkmark & \checkmark & \checkmark & ? & \cdots & ? \end{pmatrix}$$

Matrix completion equation

- Assume that the equation of interest is:

$$Y_{it} = \delta_{it} D_{it} + L_{it} + \mathbf{x}_{it}\boldsymbol{\beta} + \alpha_i + \mu_t + \varepsilon_{it}, \tag{1}$$

- Denote with $\mathcal{P}$ the set of treated unit/periods and with $\mathcal{O}$ that of untreated unit/periods.

Matrix completion estimator

$$\min_{\mathbf{L},\boldsymbol{\beta},\delta,\gamma,\lambda} \frac{1}{|\mathcal{O}|} \sum_{(i,t)\in\mathcal{O}} \left(Y_{it} - L_{it} - \mathbf{X}_{it}\boldsymbol{\beta} - \delta_t - \gamma_i\right)^2 + \lambda||\mathbf{L}||.$$

- Parameters δ and $\boldsymbol{\beta}$ and γ can be partialed out.
- Parameters $\mathbf{L}$ are estimated using an iterative procedure that relies on singular value decomposition.
- The parameter λ is estimated via cross-validation of minimized mean-squared prediction error.

Given the estimated parameters, estimated ATT is simply

$$\widehat{ATT} = \frac{1}{|\mathcal{P}|} \sum_{(i,t)\in\mathcal{P}} \left(Y_{it} - \widehat{Y}_{it}\right).$$

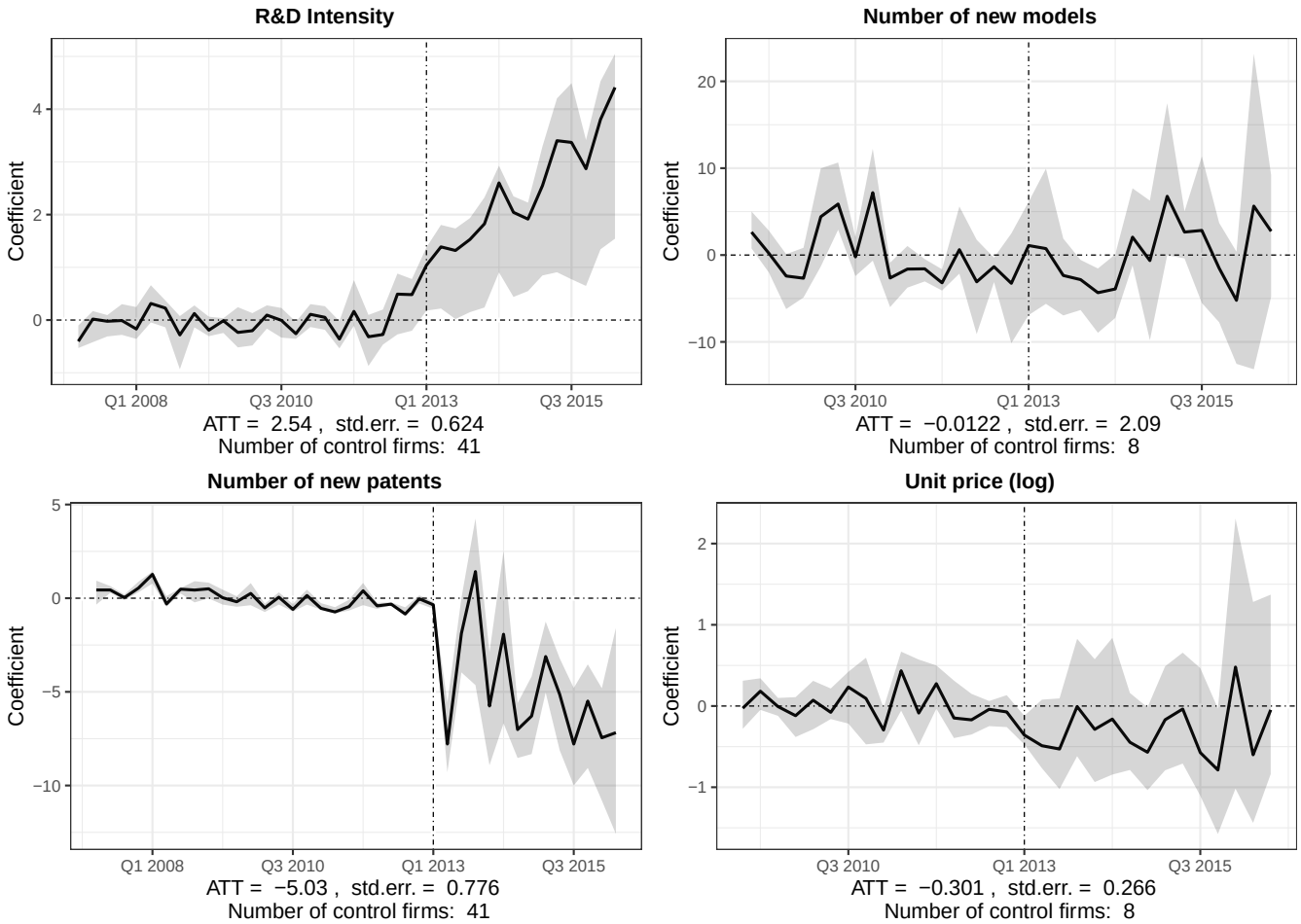
Standard errors are bootstrapped (wild).

Control firms - 42 firms

Advanced Micro Devices Inc. (NasdaqCM:AMD)
Alcatel-Lucent
Apple Inc. (NasdaqGS:AAPL)
Applied Materials Inc. (NasdaqGS:AMAT)
Atmel Corporation
Broadcom Limited (NasdaqGS:AVGO)
Canon Inc. (TSE:7751)
Casio Computer Co. Ltd. (TSE:6952)
Cisco Systems Inc. (NasdaqGS:CSCO)
Cypress Semiconductor Corporation (NasdaqGS:CY)
Dell Technologies Inc. (NYSE:DVMT)
Dongbu HiTek Co. Ltd. (KOSE:A000990)
HP Inc. (NYSE:HPQ)
Hon Hai Precision Industry Co. Ltd. (TSEC:2317)
Infineon Technologies AG (XTRA:IFX)
Intel Corporation (NasdaqGS:INTC)
IBM Corporation (NYSE:IBM)
LG Electronics Inc. (KOSE:A066570)
Lenovo Group Limited (SEHK:992)
Lite-On Technology Corporation (TSEC:2301)
Macronix International Co. Ltd. (TSEC:2337)
Micron Technology Inc. (NasdaqGS:MU)
Microsemi Corporation (NasdaqGS:MSCC)
Microsoft Corporation (NasdaqGS:MSFT)
NEC Corporation (TSE:6701)
NXP Semiconductors N.V. (NasdaqGS:NXPI)
Nanya Technology Corporation (TSEC:2408)
NetApp Inc. (NasdaqGS:NTAP)
Oki Electric Industry Co. Ltd. (TSE:6703)
Phison Electronics Corporation (GTSM:8299)
Powerchip Technology Corp.
QUALCOMM Incorporated (NasdaqGS:QCOM)
SK Hynix Inc. (KOSE:A000660)
STMicroelectronics N.V. (ENXTPA:STM)
SanDisk LLC
Seiko Epson Corporation (TSE:6724)
Sharp Corporation (TSE:6753)
Silicon Motion Technology Corporation (NasdaqGS:SIMO)
Taiwan Semiconductor Manufacturing Company Limited (TSEC:2330)
Texas Instruments Incorporated (NasdaqGS:TXN)
United Microelectronics Corporation (TSEC:2303)
Winbond Electronics Corporation (TSEC:2344)

RESULTS

Pooled ATT estimates using synthetic control



Individual ATT estimates using synthetic control

	R&D Int	Number of new patents	Number of new models	Unit price (log)
Seagate	2.740***	-4.840***	4.120***	-0.392
s.e.	(0.605)	(0.132)	(0.550)	(0.400)
WD	2.340***	-4.450***	-4.940***	-0.349
s.e.	(0.534)	(0.113)	(0.462)	(0.329)
Toshiba		-7.100***	0.845***	-0.453***
s.e.		(0.210)	(0.136)	(0.175)
Pooled	2.540***	-5.030***	-0.0122	-0.301
s.e.	(0.621)	(0.772)	(2.070)	(0.263)
Number of control firms	41	41	8	8

INNOVATION INPUT AND OUTPUT

Innovation input and output

We tested the relationship between R&D spending and patent citations, and our measures of innovation output.

- Using matrix completion we established that there are time-variant effects of the mergers, but the method is not designed to identify what are the time-variant input causes.
- Instead, we now revert to a standard difference-in-differences approach, including the key explanatory variables, innovative inputs.

Innovation input and output

	Seagate		Western Digital	
	Number of new models	Unit price (lag)	Number of new models	Unit price (lag)
Post-merger (μ_t)	1.198***	-1.15***	1.167**	-1.134***
	(0.4359)	(0.1397)	(0.4546)	(0.1367)
Treatment effect (δ_0)	-26.646***	0.996	33.856***	1.65
	(5.827)	(1.8669)	(10.2284)	(3.077)
R&D (δ_{11})	0.231**	-0.021	0.179*	-0.019
	(0.1036)	(0.0332)	(0.1081)	(0.0325)
Patent count (δ_{21})	-0.081	0.004	0.029	-0.016
	(0.0768)	(0.0246)	(0.0697)	(0.021)
R&D x treatment effect (δ_{12})	3.746***	-0.063	-3.78***	-0.086
	(0.6237)	(0.1998)	(0.9499)	(0.2858)
Patent x treatment effect (δ_{22})	-1.424***	0.016	0.089	0.005
	(0.4983)	(0.1597)	(0.2005)	(0.0603)
p_val parallel trend	0.7475	0.756	0.4522	0.9729
N	224	224	224	224

Decomposition of effects

$$(Y_{T1} - Y_{T0}) - (Y_{C1} - Y_{C0}) = \underbrace{\delta_0 + \delta_{12} rd_{T1-L}}_{\text{R\&D productivity change}} + \underbrace{\delta_{11} rd_{DiD-L}}_{\text{R\&D change}}$$

	Seagate		Western Digital	
	Number of new models	Unit price (lag)	Number of new models	Unit price (lag)
Joint R&D effect	6.253***	0.417	-6.133**	0.707
	(1.6863)	(0.5403)	(2.5558)	(0.7689)
R&D increase	0.385**	-0.036	0.265*	-0.028
	(0.1731)	(0.0554)	(0.1601)	(0.0482)
Productivity	5.868***	0.453	-6.398**	0.735
	(1.6986)	(0.5442)	(2.564)	(0.7713)

Interpretation of findings - Seagate

- Increase in R&D and the productivity of R&D for new models.
- No effect on unit price.
- A number of alternative interpretations:
  - There were innovation synergies between Seagate and Samsung, which were corroborated by the merger.
  - Elimination of duplications between Seagate's and Samsung's production and R&D lines.
  - Unit price drops at similar rate as for SSD.

Interpretation of findings - Western Digital

- Mixed findings (increase in R&D but drop in patents, and negative effect on productivity)
- Possible interpretations:
  - The MOFCOM decisions particularly hindered the consummation of the WD/HGST merger until October 2015. Remedies blocked their ability to remove duplications, which could have affected innovation productivity. This might also explain some of the increase in R&D (i.e. duplicated spending for the units held separate).
  - The need to divest the 3.5in operations of HGST.

Interpretation of findings - Toshiba

- Positive findings (drop in patents, improvement in new models and unit price, improved productivity of R&D and patents).
- Possible interpretations:
  - R&D figures include Toshiba's other segments (around 25% of Toshiba's revenue comes from storage related operations).
  - Toshiba acquisition of HGST was the result of a divestiture condition imposed on the other two merging firms - evidence that the divestiture was successful.

CONCLUSION

Lessons learned

- Challenges in conducting similar case studies.
- Large mergers:
  - Worldwide markets and innovation,
  - Might be more confounding effects, regulatory delay, etc
- Small mergers:
  - Less data (R&D data is unlikely for small firms and patent data is more likely to be sparse),
  - But simple product characteristics might be measurable

Lessons learned

- A lot of the data was free to access (except the balance sheet data)
- R&D data is unlikely to be available by segments.
- We show the problem caused by using a single measure of innovation (R&D or patents).
- Patent or new product data are count data - challenges in using causal inference methods for such data.
- Strategic substitute or complements? Lack of theory or empirical works.
- This paper also demonstrated the difficulty of claiming a one-size-fits-all relationship between competition and innovation. Innovation levels changed differently for the three HDD manufacturers.

EXTRA SLIDES

Discussing our assumptions - Independence

If the control is not independent then the effect of the mergers is spilled over to the control group.

- EC decision and industry report pitch SSD as a separate (vertically differentiated) market
- But if there is dependence between the level of innovation in the two technologies, is that driven by strategic complementarity or substitutability across innovation decisions in the two technologies
  - if HDD increases innovation, will it reduce (strategic substitutes)
  - or increase (strategic complements) innovation in SSD.
- To our best knowledge, up to date, no empirical evidence has been provided on this.

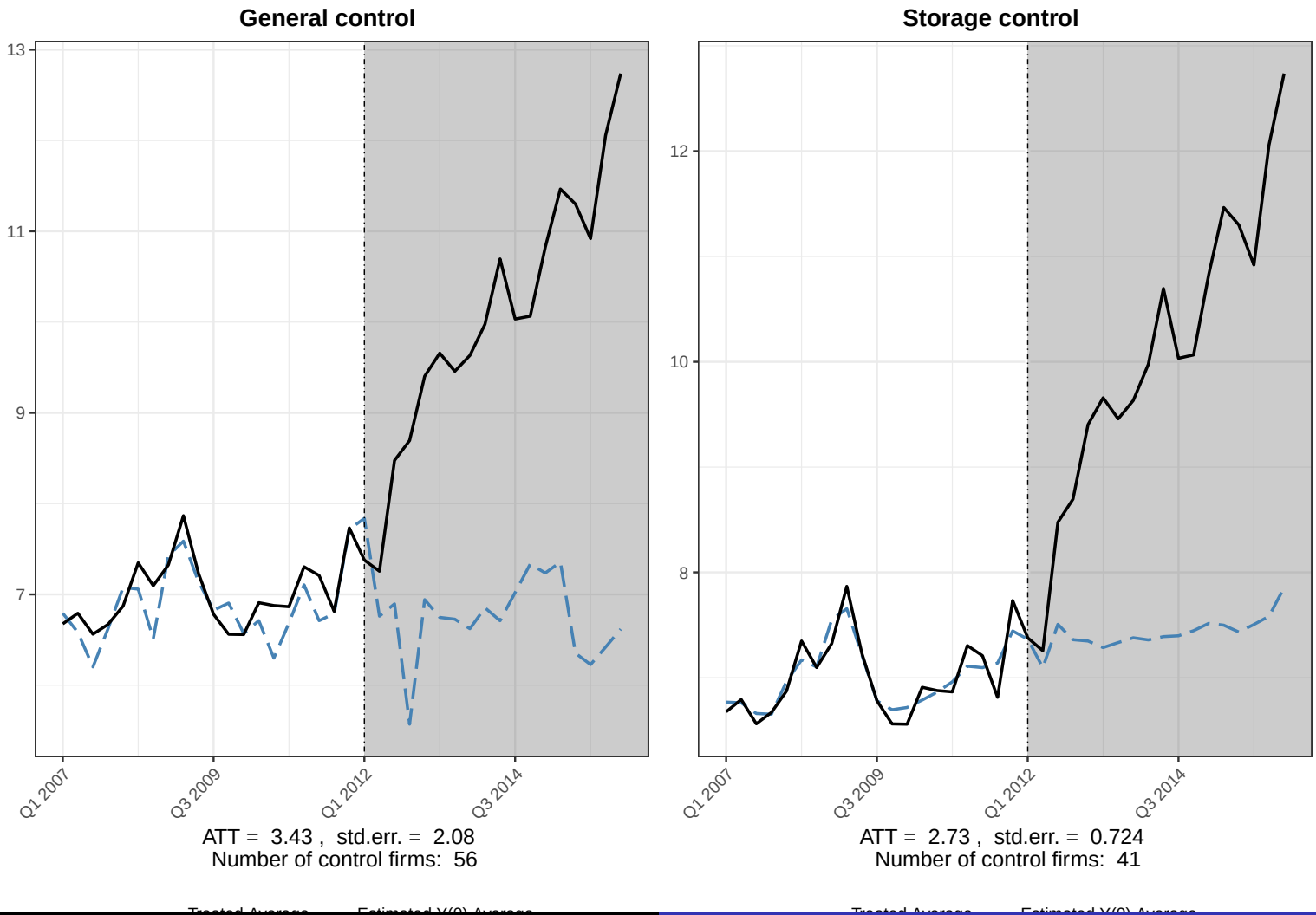
Discussing our assumptions - Independence

We compared two potential control groups:

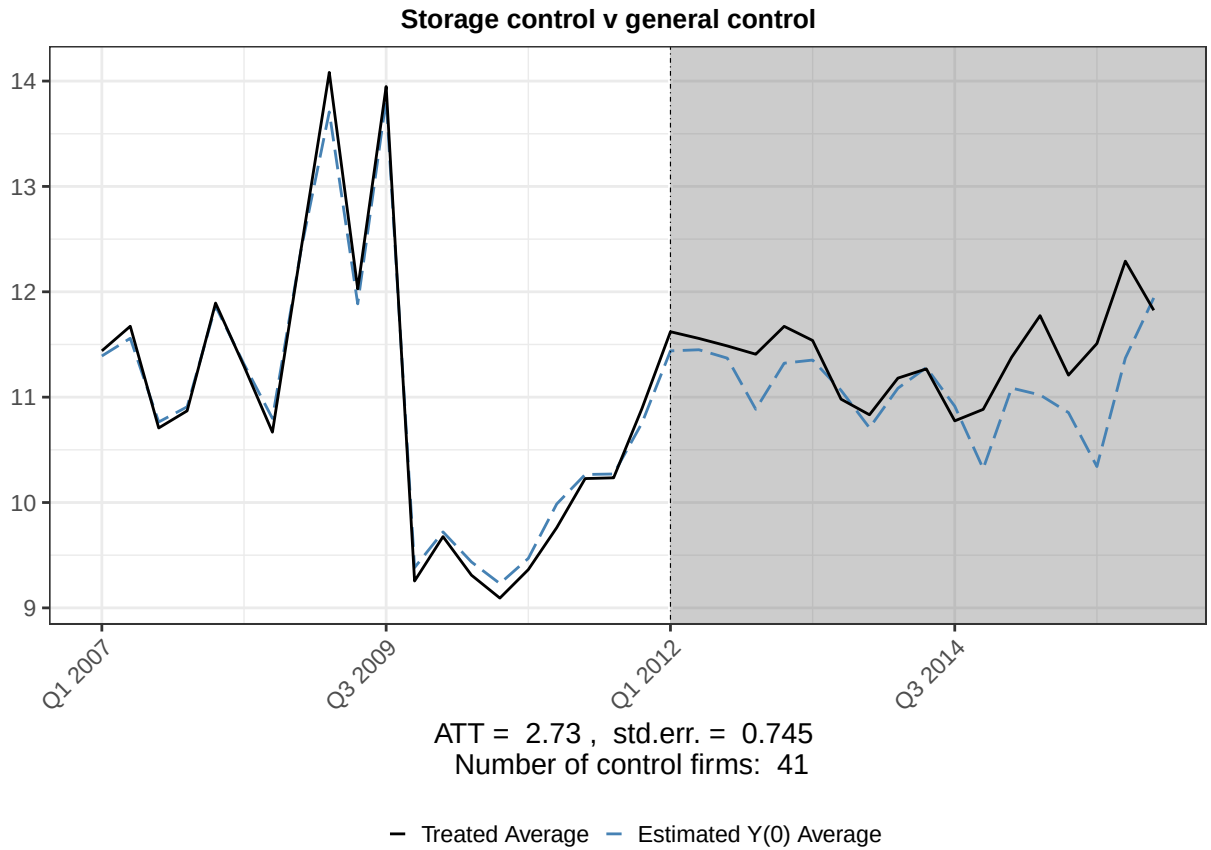
- one that is very likely independent (a synthetic composition of IT firms (within 2 digit sic codes)
- and one that is potentially affected by the strategic relationship, Flash/SSD manufacturers ('Storage control').

If Flash/SSD R&D activity is unaffected by the mergers, then post-merger the Storage control response to the merger will be similar to the General control's response.

Discussing our assumptions - Independence



Taken at its face value this would suggest that R&D spending in the group where there might be a suspicion of being confounded (Flash/SSD) is no different from the group where we can more confidently assume independence.



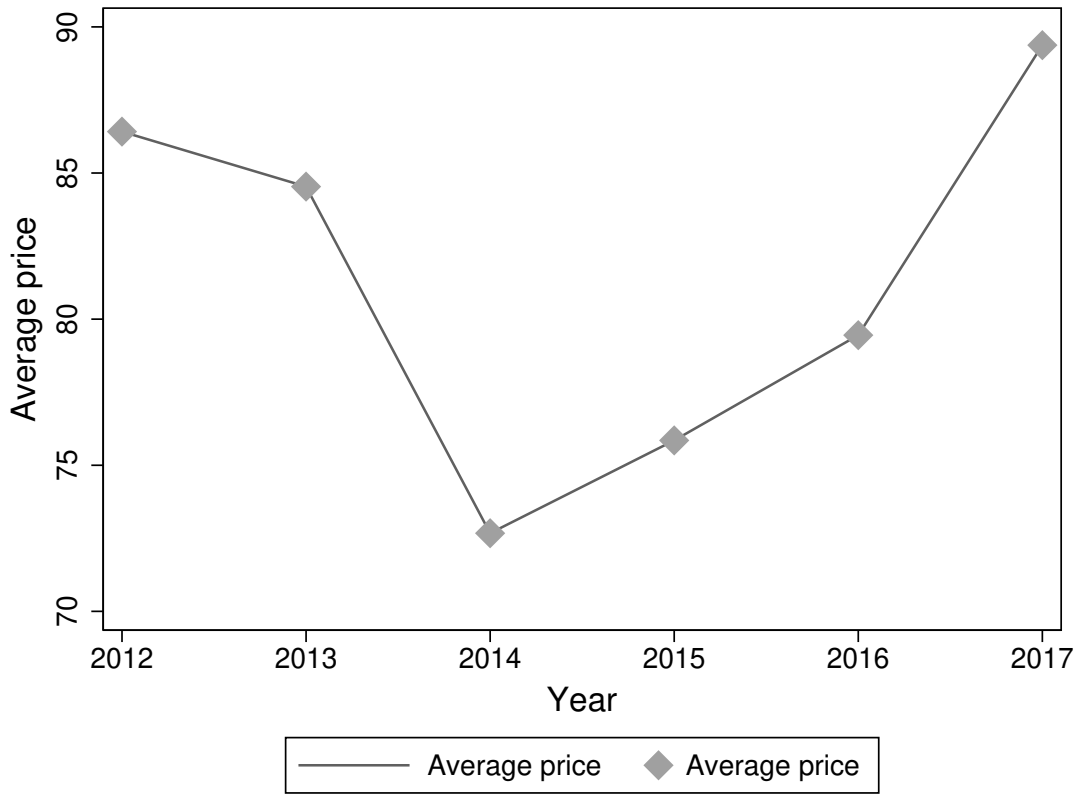
Outcome variable - Unit price (USD/Gb)

For this we needed:

- **Storage capacity:** Ideally, one would have looked at areal density. However using retail data we had limited access to technological details and could only measure formatted capacity (expressed in Gb). This also allowed comparisons with SSD. Capacity alone does not give an unambiguous picture of innovation because newer products do not necessarily mean larger capacity.
- **Retail price:** Prices as collected in 2018 (e.g. for an HDD that was first marketed in 2012, we had the price as it appeared in 2018). Seems to go against intuition, as one could expect prices to gradually fall (i.e. price of older products would always be smaller than the price for newer products). This however does not seem to be the case for HDDs.

Outcome variables - Unit price (USD/Gb)

Figure: Historical prices of a sample of HDDs (USD)



Endogenous merger

For unbiased DiD estimates one would also have to assume that the treatment (the mergers) was exogenous. Potential sources of endogeneity:

- Reverse causality: when a drastic change in the outcome variable (innovation activity) is one of the reasons for the merger to take place.
- Self-selection: firms that merge could be the more productive ones, i.e. those that would have become more innovative even without a merger.
- The decision to merge was triggered by unobservable time varying factors, such as technology and/or demand shocks, which affect both the decision to merge and the outcome variable.