

A New Look at Prices of Personal Computers, Tablets, and Cell Phones: *A Progress Report*

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Based on work with

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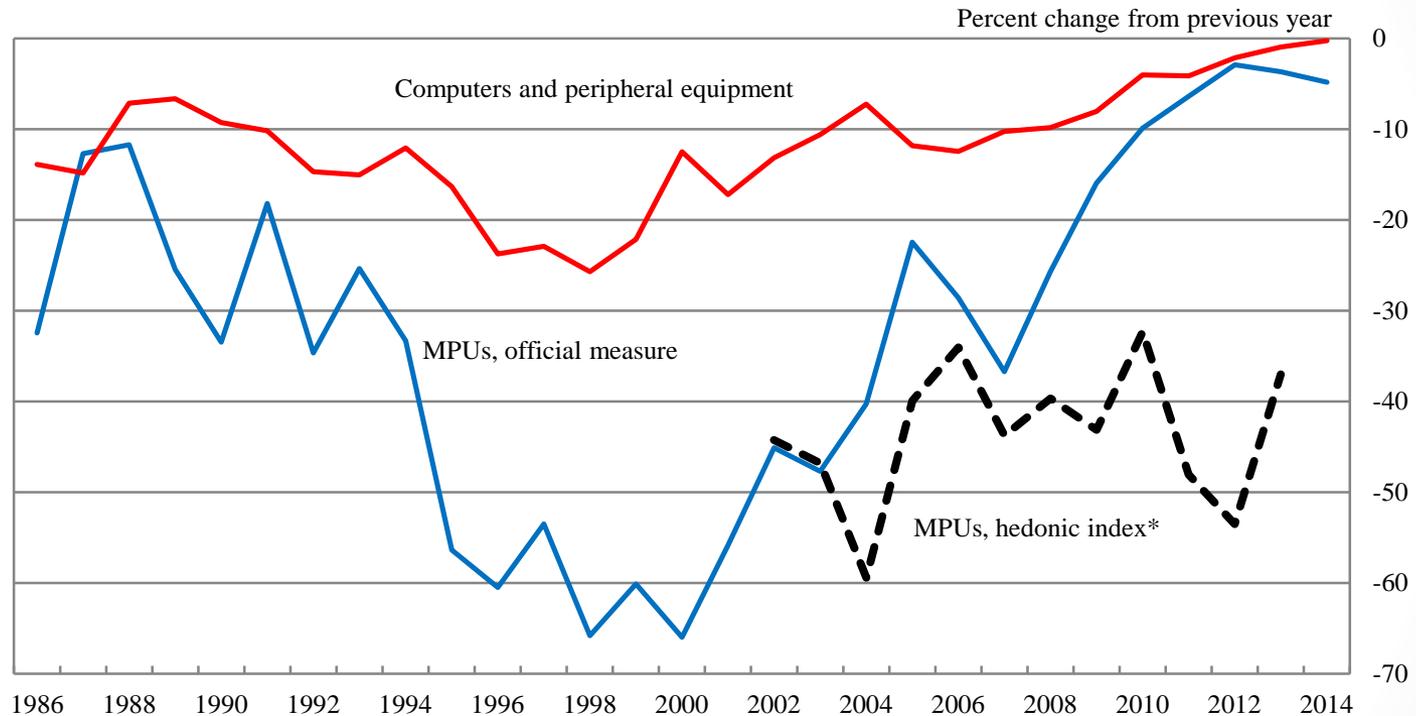
BEA Advisory Committee Meeting

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Motivation

- Official price measures for many high-tech devices are falling very slowly.
- Often interpreted that pace of innovation has slowed.
- But, several recent studies suggest that official price measures are understating the decline.

Price Indexes for Computers and Microprocessors



*Plotted as a 2-year moving average to smooth annual variation.

Sources. Computers and peripheral equipment, Bureau of Economic Analysis (NIPA table 5.3.4); MPUs, official measure, Byrne, Oliner, and Sichel (2015), using data from Grimm (1998, table 12) for 1986-92, Federal Reserve Board for 1993-97, and Bureau of Labor Statistics for 1998-2014; MPUs, hedonic index: Byrne, Oliner, and Sichel (2015).

Two questions

- What do hedonics show for recent prices for personal computers, tablets, and cell phones?
- Does the use of performance benchmarks matter for hedonics for these devices?



Summary of Results

- Desktop PCs: hedonic price indexes falling about 15% 2007-2010, more slowly thereafter.
- Tablets: hedonic price indexes generally falling more rapidly than for desktops; no slowdown more recently.
- Phones, rugged tablets, and laptop PCs: Still to come – not talking about today.

Assembled Several Datasets

	Prices and technical characteristics	Performance benchmarks
Desktop & Laptop PCs	NPD	SPEC, Passmark
Tablets	NPD	Passmark, Geekbench
Cell phones	IDC	Passmark, Geekbench

Data Details, Prices and Characteristics

	Time Span	Number of Qtrly Observations
Desktop PCs	Jan 2007 - Dec 2014	46,231
Laptops	Jan 2007 – Dec 2014	83,722
Tablets	Jan 2007-Dec 2014	8,127
Smart phones	2007:Q1 - 2015:Q3	3,849
Non-smart phones	2007:Q1-2015:Q3	646

Performance Benchmarks

- Benchmarks measure actual performance
- Benchmarks matched to observations on prices/characteristics by model.
- Desktop matches: 64.5 % of models
- Tablet matches:

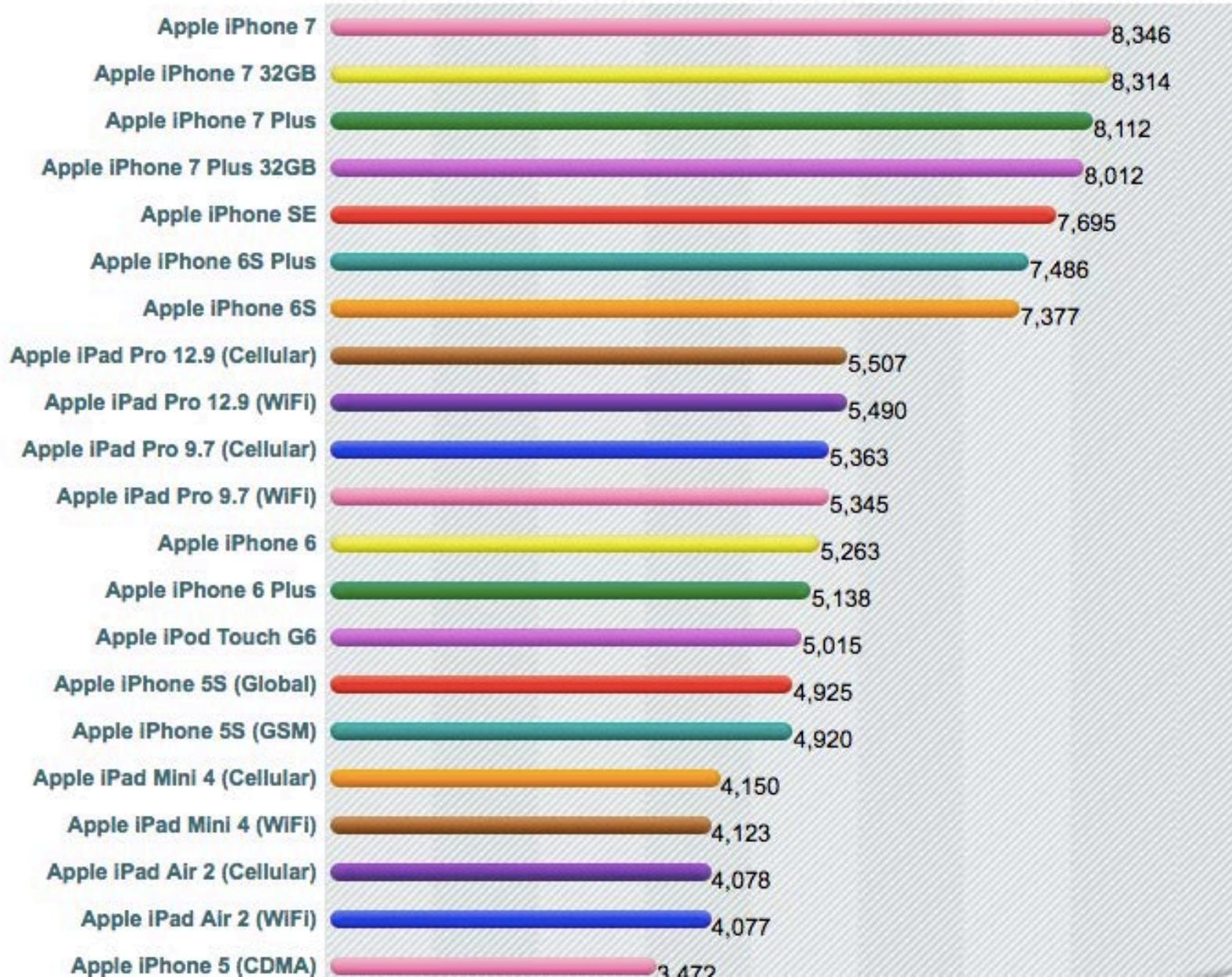
Apple	100%,
Microsoft	87
Samsung	53

Obtaining Performance Metrics

- **Hard work!**
- Web-scraping. Some automated matches, some matching by hand
- Different measures available for different devices
- Need to go where market provides benchmarks

iOS PassMark Rating

Updated 18th of November 2016



Apple iPad Pro 12.9 (Cellular)

General information and performance details for Apple iPad Pro 12.9 (Cellular) can be found below. This is made using thousands of **PerformanceTest Mobile** benchmark results and is updated daily.

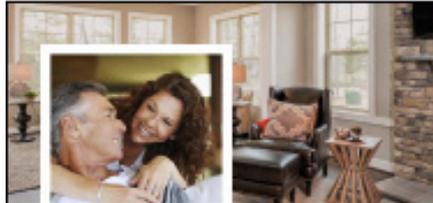
- The first graph shows the relative performance of the device compared to 10 other common devices in terms of PassMark iOS CPU Mark.
- The 2nd graph lists up to the last 5 baseline submissions for this particular device.

How does your device compare

Add your device to our benchmark chart with **PerformanceTest Mobile**

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Apple iPad Pro 12.9 (Cellular)

CPU Speed	0 MHz
Number of Cores	2
Total RAM	3990.8 MB
Most Common OS	iOS iPhone OS 10.0.2
Average CPU Mark	55,964
Average Mem Mark	16,211
Average Disk Mark	100,608
Average 2D Mark	4,200
Average 3D Mark	1,176

**Average PassMark
Rating**

5,507

Rank: 8
Samples: 175

First Benchmarked:
Mar 23 2016

Desktop PC Hedonic Regressions

- **Hedonics**
 - Adjacent-year
 - Adjacent-quarter
 - Chained Fisher with cross-section regression for each quarter
- **Weighted for revenue shares** [following Diewert, Heravi, and Silver (2008)]

Desktop PC Hedonic Regressions (cont)

- **Explanatory variables:**
 - **Technical characteristics:**
 - Clock speed of CPU
 - RAM
 - Hard disk size
 - Thermal design power (power use)
 - Brand
 - Operating system
 - Type of graphics processor
 - Small footprint
 - Shared memory between main CPU and GPU
 - Marketed to commercial users
 - **Performance benchmarks:**
 - Passmark CPU Benchmark

Desktop Prices

	2007-10	2010-14	2007-14
	Average percent change		
Average price	-5.5	.6	-2.0
Matched-model	-7.6	-5.1	-6.2

- Matched-model captures some quality change.

Desktop Prices: Adjacent-year regressions

	2007-10	2010-14	2007-14
	Average percent change		
Average price	-5.5	.6	-2.0
Matched-model	-7.6	-5.1	-6.2
Technical characteristics	-14.0	.7	-5.6

- Hedonic with technical characteristics: faster declines than M-M before 2010, similar declines after.

Desktop Prices: Adjacent-year regressions

	2007-10	2010-14	2007-14
	Average percent change		
Average price	-5.5	.6	-2.0
Matched-model	-7.6	-5.1	-6.2
Technical characteristics	-14.0	.7	-5.6
Performance & tech characteristics	-15.3	-3.8	-8.7

- Hedonic with performance falls **3 pct pts** faster than technicals alone
- R^2 higher with performance
- Prices falling slowly recently
- Quality improvements not valued that highly

Desktop Prices: Adjacent-year regressions

	2007-10	2010-14	2007-14
	Average percent change		
Average price	-5.5	.6	-2.0
Matched-model	-7.6	-5.1	-6.2
Technical characteristics	-14.0	.7	-5.6
Performance & tech characteristics	-15.3	-3.8	-8.7
Performance & tech, excl. clock speed	-15.1	-4.2	-8.9

- Dropping clock speed: makes little difference to price trends or R^2 .

Adjacent-quarter and Fisher Chain Indices

	2007-10	2010-14	2007-14
	Average percent change		
Adjacent quarter	-17.3	-6.1	-10.9
Fisher chain, quarterly	-16.6	-6.8	-11.0
Memo: Adjacent year	-15.1	-4.2	-8.9

- Quarterly indexes drop about **2 pct pts** faster than adjacent-year indexes

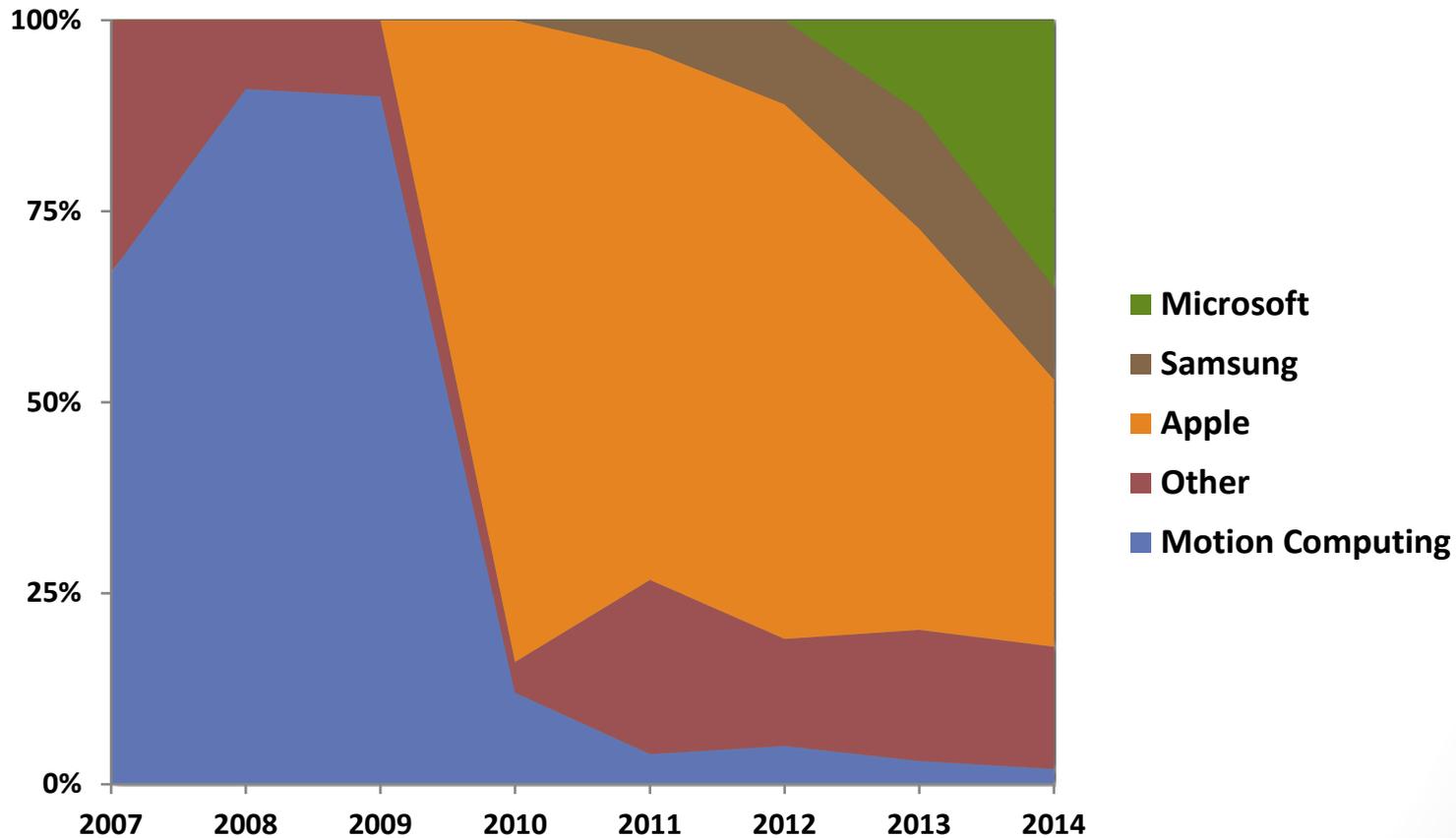
Desktop PC Prices: Bottom Line

- Price declines slowed in recent years.
- Desktop PCs a mature product
 - Quality improvements not valued that highly
- Performance measures useful for capturing quality change; extra explanatory power not dramatic.

Tablets

- **Two market segments:**
 - iPad and competitors
 - Starts 2010
 - Specialized commercial (“rugged”)
 - Starts before 2010

Market Shares for Tablets



Tablet Markets

- Before 2010, Motion Computing and Panasonic were dominant players in specialized commercial
- iPad exploded in 2010; Apple had **84%** share
- Competitors have taken share from Apple
- Consider key brands separately

Hedonics for Tablets

- **Same setup as for desktops:**
 - Adjacent-year regressions
 - Revenue-share weighted

Hedonics for Tablets

- **Explanatory variables:**
 - **Technical characteristics**
 - Clock speed
 - Flash memory amount
 - Weight
 - Screen size
 - Battery capacity
 - **Performance benchmarks**
 - *Apple & Samsung*: Passmark (CPU, memory, disk, 2D graphics, & 3D graphics)
 - *Microsoft*: Geekbench (single-core score)

Tablet Prices¹

	Apple	Samsung	Microsoft
	average percent change		
	2010-14	2011-14	2013-14
Average price	-7.4	-20.5	-7.9

¹Microsoft based on unweighted regressions.

- Average prices fell for Apple, Samsung, and Microsoft

Quality Change

- Latest generation Apple iPad compared with first generation:
 - 2x clockspeed
 - 2x cores
 - 8x memory
 - 2x screen resolution
 - Weighs 1/3 less
 - Half thickness
 - Includes sophisticated camera

Tablet Prices

	Apple	Samsung	Microsoft
	average percent change		
	2010-14	2011-14	2013-14
Average price	-7.4	-20.5	-7.9
<i>Hedonics</i>			
Technicals	-10.3	-21.8	-26.5

Tablet Prices

	Apple	Samsung	Microsoft
	average percent change		
	2010-14	2011-14	2013-14
Average price	-7.4	-20.5	-7.9
<i>Hedonics</i>			
Technicals	-10.3	-21.8	-26.5
Performance & Tech	-10.5	-23.0	-26.6
Performance & Tech, excl. speed	-9.7		-27.0

- Apple with performance ↓ 10% / yr
- Samsung & Microsoft ↓ about 25% / yr

Tablets: Bottom Line

- **iPad and competitors:**
 - Prices falling relatively rapidly during period when desktop price declines stalled.
 - Newer products; locus of innovation
 - Results similar to Byrne, Dunn, and Pinto who use different data and methodology

Two questions

- **What do hedonics show for recent prices of personal computers, tablets, and cell phones?**
 - **Desktops:** prices falling slowly in recent years. A mature product.
 - **Tablets:** prices falling more rapidly; locus of innovation.



Two questions

- **Does the use of performance measures matter for hedonics for these devices?**
 - **Yes.** We believe performance measures should be used in hedonics whenever possible.
 - For products with multi-dimensional quality,
 - Harder to get performance measures that are sufficient statistics for quality
 - Other tech features (like operating system) appear to be correlated with performance

Still to come

- Hedonic price indexes for laptops, rugged tablets, and cell phones
- Complete coverage of tablets
- Robustness and sample selectivity checks
- Compare with official statistics

Comparison to Official Computer Indexes

	2007-10	2010-14	2007-14
	Average percent change		
Fisher chain, quarterly	-16.6	-6.8	-11.0
PPI, PCs & Workstations	-23.3	-11.4	-16.5
BEA investment deflator, CPE	-7.6	-1.8	-4.3
Import prices, Computers (BLS, Dec-Dec)	-2.6	-2.5	-2.5

- Need to fill in laptops and tablets to make comparisons.
- Import prices fall **very** slowly.