FEDS Notes

Print

July 1, 2015

Prices for Data Storage Equipment and the State of IT Innovation

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Innovation in information technology (IT) has been the subject of considerable debate recently. Plausible quantitative estimates are not available for the labor productivity contributions from the new wave of IT--smartphones, tablets, cloud computing, and the myriad applications these platforms make possible--fueling wildly different subjective appraisals of their importance relative to old-wave IT--such as personal computers and office productivity software. This note presents new estimates of price trends for data storage equipment, a key general-purpose technology that enables both emerging and mature IT applications. The results provide a mixed signal for the debate about IT and productivity: Storage equipment prices have fallen far faster than official price indexes indicate, but there has been a shift since 2009 to more moderate, albeit still rapid, price declines.

Data Storage Technology

Data storage devices preserve information digitally for repeated use over long periods of time. They consist of the medium used to record data and the associated controllers, racks, and cables used in conjunction with specialized communication switches to serve computing equipment. Currently prominent technologies include magnetic storage in the form of hard disk drives (HDDs) and circuit boards with arrays of flash memory chips, known as solid state drives (SSDs). Tape drives, formerly the most prevalent technology, are still used in specialized applications. HDDs are currently the dominant technology for large-scale applications because of their low cost. SSDs, which are more expensive per unit of stored information but have more rapid response times, have increasingly been used in large-scale applications as well.

Features of storage devices which affect their value to users include capacity (areal density), bandwidth (rate of data transmission), latency (time from request to beginning of transmission), dependability (protection against loss of data), and scalability. With respect to HDD technology, the areal density of leading-edge magnetic disks increased at a rate of 30 percent per year from 2003 to 2010, but has slowed to roughly 10 percent annual growth since then.[2] For flash chips, feature density nearly doubled annually from 2000 to 2010. Although increases in density per square inch have slowed since then, the industry has augmented capacity gains by introducing design changes such as multi-layer chips (MLCs).[3]

In addition to capacity improvements, performance enhancements for storage devices have come from increases in bandwidth and decreases in latency derived from disk configuration improvements and the adoption of better specialized internal processors to manage data requests. Hardware and software schemes have raised dependability through redundant data records, and current storage systems are designed to allow equipment installations to ramp up to a massive scale. These engineering advances may be expected to underpin declines in quality-adjusted prices.

Storage Equipment Prices and Deflation of Industry Production

A price index for large-scale storage devices (devices with 3 or more disks) was constructed using quarterly-frequency data covering 2002 to 2014 from IDC, Inc. These data include factory revenue in U.S. dollars and units shipped to the global market for 703 models. Shipments were further distinguished by installation type (*e.g.*, network attached storage, storage area network), protocol (e.g. Infiniband, iSCSI), redundancy (*e.g.*, RAID, JBOD), and multiprotocol capability, yielding 1,564 distinct items. On average, these items remain in the market for 11 quarters. Prices were constructed by dividing revenue by terabytes of capacity shipped. To construct a price index, a "matched-model" approach was used; that is, changes in price per terabyte for identical items were chain-weighted using revenue weights to construct an overall index. This technique credibly accounts for quality improvement in this case because the items are distinguished by price-relevant characteristics, high-frequency price observations are used, and the market is competitive enough that the entry of new products with lower price-performance ratios is likely to drive down the price of incumbent products.[4] The price index for large-scale systems fell 27.8 percent in the period covered by the data (table 1).

Table 1: Alternative Price Indexes for Data Storage Equipment

Year	FRB Product Series	FRB Industry Series	BLS Product Series	BLS Industry Series	BLS Import Series	BEA Investment Series
2002	1010.49	589.60	357.24	160.71	148.53	153.86
2003	647.48	422.60	274.08	138.74	138.61	137.92
2004	418.59	298.92	207.02	122.96	129.01	125.04
2005	288.60	226.19	157.46	114.70	122.19	117.46

Year	FRB Product Series	FRB Industry Series	BLS Product Series	BLS Industry Series	BLS Import Series	BEA Investment Series
2006	188.63	164.23	122.44	106.02	115.31	109.52
2007	133.86	125.34	109.18	102.21	107.73	104.29
2008	100.00	100.00	100.00	100.00	100.00	100.00
2009	69.72	75.13	88.60	89.75	93.47	91.12
2010	56.87	62.70	82.04	76.87	91.00	81.84
2011	43.74	49.99	82.35	75.89	87.06	79.89
2012	34.94	41.01	94.28	76.77	88.14	81.00
2013	27.93	33.97	87.12	71.93	87.67	77.65
2014	20.21	25.64	84.87	70.41	86.04	75.93
2002-14	-27.8%	-23.0%	-11.3%	-6.6%	-4.4%	-5.7%
2004-09	-30.1%	-24.1%	-15.6%	-6.1%	-6.2%	-6.1%
2009-14	-21.9%	-19.3%	-0.9%	-4.7%	-1.6%	-3.6%

Source. Federal Reserve Board indexes are based on data from IDC, Inc.; BLS Producer Price Index is from the Bureau of Labor Statistics, http://www.bls.gov/ppi; BLS import price is index for "computer accessories, peripherals and parts" from Bureau of Labor Statistics, http://www.bls.gov/mxp; and BEA data are from the "Final Sales of Domestic Computers" spreadsheet from Bureau of Economic Analysis website, accessed June 26, 2013. BEA prices for 2013 and 2014 are extending using a geometric mean of the BLS product and BLS import price indexes.

Note. FRB 2014 index level based on first through third quarters, seasonally adjusted. Large-scale systems contain three or more disk drives. All indexes rebased to 2008 = 100.

More limited data was available for small-scale storage systems. Quarterly-frequency factory revenue and unit data on systems designed for personal or small-office use, grouped by disk diameter, were acquired from IDC for 2008 to 2014. A price index for small-scale systems built from average price per gigabyte by disk diameter fell 22.5 percent from 2008 to 2014, roughly the same rate as the price index for large-scale systems in this period. In light of the close alignment of the small-scale and large-scale price indexes, the more extensive large-scale index is used as an indicator for overall price trends for data storage equipment.

The new price index falls 16.5 percentage points faster per year than the Bureau of Labor Statistics producer price index for this class of products (table 1). There are several possible explanations for the significantly different trends in the indexes:

- *Product coverage:* Some storage device types are omitted from the research index due to lack of data, most notably tape drive systems and optical drives. However, the omitted devices are believed to account for a negligible share of U.S. domestic production in recent years.[5]
- *Item weights:* The research index uses revenues to weight individual item price series, in contrast to the BLS PPI, which does not collect item-level weights. The revenue weights have the advantage of allowing the index to account for a greater share of the substitution among products in response to changing relative prices.
- *Product composition:* The composition of the global shipments reported in the IDC data is undoubtedly different from domestic shipments, a potential drawback for deflation of domestic production, but because the global IT market is highly integrated, the data may provide a reasonable proxy for domestic prices. With this question in mind, an index was constructed using solely data on products from EMC Inc., a company which accounts for a major share of the domestic industry. The index fell at roughly the same average rate as the index for all products, suggesting the difference in price trends between domestic and foreign producers is not a major concern.
- *Explicit quality adjustment for entering products:* BLS PPI methodology allows for adjustment of the price of items newly introduced to the index to account for the premium paid for any difference in characteristics relative to continuing items if survey respondents provide sufficient information to price the new features.[6] This approach was not employed in the Federal Reserve index discussed here.
- *Variation in capacity shipped by item:* The data employed for the research index indicate that on average, capacity for a marketed item increases at an average annual rate of 34 percent over the life-cycle, which indicates that controlling for capacity *within item series* is critical. The research index addresses this issue by constructing a price per terabyte for each item, whereas the BLS methodology, as discussed above, allows for the use of explicit quality adjustment *when respondents provide the marginal price charged for additional capacity*. To illustrate the importance of this dimension, a price index was constructed employing price per machine, rather than price per capacity unit, which fell at an average annual rate of 5.7 percent--22 percentage points slower than when capacity was accounted for.

The Federal Reserve will employ the research index in the construction of the Industrial Production Index beginning with the 2015 annual revision. The underlying data appear to be well-suited to capturing market price trends, substitution in response to price shifts, and capacity increases within product series, and they yield a price index better aligned with technical trends in the industry. For use as an industry price index in IP, the large-scale product price index is aggregated with BLS price series for parts and accessories, for secondary products, and for miscellaneous receipts using weights from the Census Bureau's Economic Census and Annual Survey of Manufactures. The IP industry price index falls at an average annual rate of 23.0 percent from 2002 to 2014 (table 1). The BLS PPI industry index, formerly used to deflate the production of this industry, declines at an annual rate of 6.6 percent during this period. In 2012, data storage equipment accounted for about one-third of production of computers and peripheral equipment.

Implications for IT Investment

The implications of these research results for IT investment are somewhat complicated. The BEA index used for deflating investment in data storage equipment, which is a weighted average of the BLS industry PPI and the BLS price index for imported computer accessories, peripherals, and parts falls at an average annual rate of 5.7 percent during the 2002 to 2012 period (table 1). If the research index for storage equipment products were used, storage equipment investment would climb appreciably faster throughout this period.[7] Interestingly, declines in the new index have moderated somewhat in recent years, averaging 21.9 percent from 2009 to 2014 compared to 30.1 percent from 2002 to 2009.[8] As discussed in a previous FEDS Note, declines in the BEA investment price index for IT equipment have slowed dramatically in recent years and the source of the slowdown is the investment price index for computers and peripheral equipment, of which data storage equipment is a part.[9] The moderation in storage equipment price declines shown by the research index is consistent with the slowdown in the prices for the broader IT equipment aggregates. If the price index based on the research described here were adopted to deflate nominal investment in storage equipment in place of the slower-falling BEA index, the price index for computers and peripheral equipment would decline roughly 1 percentage point faster in both periods and would not materially change the swing in price changes between the periods.[10]

Unfortunately, these data do not extend back far enough to compare current price trends to the "IT Boom" period of the late 1990s. However, engineering advances are known to have slowed. The areal density of HDDs was increasing at a blistering rate during that period--doubling every year--suggesting that storage equipment prices may have been falling even faster during the boom than in recent years (table 2; see Hennessy and Patterson (2012)). Webb (2011) presents evidence that retail prices for single HDDs (per megabyte) fell 57.2 percent (annual rate) from 1995 to 2000, then slowed to 40.5 percent from 2000 to 2010.[11] Consequently, it is reasonable to assume storage equipment prices were falling even faster during that period than the declines recorded for the research index from 2002 to 2014.

Table 2: Approximate Rates of Technical Advance For Data Storage Equipment

Time Period	Areal Density	Price per Gigabyte Webb	Price per Gigabyte McCallum
1988-1996	60%	-48%	-40%
1996-2003	100%	-52%	-51%
2003-2010	30%	-35%	-34%
2010-2014	10%		-13%

Source. Areal density from Hennessey and Patterson (2012) 1988-2010, Coughlin (2014) 2010-2014; Price per gigabyte from Webb (2011), and McCallum, available at http://www.jcmit.com/diskprice.htm

Notes. In 2011, flooding damaged a substantial portion of the global hard disk supply chain. Prices for hard disk drives rose 63 percent in 2012.

Conclusion

The new price index presented here, constructed for use in the Federal Reserve Board's Industrial Production Index, indicates that from 2002 to 2014, quality-adjusted prices for data storage equipment fell at an average annual rate of nearly 30 percent, providing quantitative evidence that IT equipment innovation continues at a solid rate. This general-purpose technology plays a prominent role in enabling new IT applications such as services delivered over smartphones and tablets and in continued advances in more mature enterprise applications. To the extent that complementary investment takes place, for example in software and business organization, to exploit ever-cheaper storage capacity, this equipment may be expected to support labor productivity gains in the future. That being said, the research index indicates that prices for data storage equipment have fallen *somewhat* more slowly since 2009 (not radically slower as official prices suggest), and while the data used do not provide an opportunity to compare the current period with the 1990s IT investment boom, other evidence points to moderation relative to that period as well.

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1. The author thanks Arthi Rabbane for research assistance and Alvin So of BLS and Christina Hovland of BEA for guidance. Return to text

2. On storage technology trends, see Hennessy and Patterson (2012), *Computer Architecture: A Quantitative Approach*. The slowdown and the emerging technology that may revive faster growth rates is discussed in "HDD Areal Density and $/TB Trends," Tom Coughlin, Forbes, December 22, 2014. Return to text

3. See the executive summaries for the 2011 and 2013 editions of the *International Technology Roadmap for Semiconductors*. Available at http://www.itrs.net.

Return to text

4. See Aizcorbe, Corrado, and Doms (2003), "When do Matched-Model and Hedonic Techniques Yield Similar Measures?" FRB of San Francisco Working Paper No. 2003-14. Return to text

5. U.S. Census Bureau Current Industrial Reports for the Computers and Electronic Products industry indicate little production for these products as of 2012, when the report series was terminated. Flash drives are counted by BLS in NAICS industry 334119 Other Computer Peripheral Equipment Manufacturing, but are counted by the Census Bureau in the storage equipment industry. In any event, domestic production of these products is negligible. Return to text

6. Explicit quality adjustment of entering products with a hedonic function was used at the time of introduction of the index in 1993 (Triplett, Jack E. "High-tech industry productivity and hedonic price indices." *OECD Proceedings: industry productivity, international comparison and measurement issues*. 1996.) "Quality-Adjusting Computer Prices in the Producer Price Index: An Overview," More recently, the practice of employing hedonics has been discontinued: Michael Holdway, retrieved January 1, 2011 referred to hedonic models used to quality-adjust disk storage arrays and this reference has been removed in more recent versions. Return to text

7. Because the research index allows for substitution between domestically-sourced and imported products, it avoids the bias introduced by using separate indexes for imports and for domestically sourced investment, as discussed in Houseman, Susan, et al. "Offshoring bias in US manufacturing." *The Journal of Economic Perspectives* (2011). Return to text

8. This slowing of price declines within the period covered by the data may be a result of the slower advances in HDD density referred to above and the shift in SSD flash technology toward more difficult 3-dimensional designs. Return to text

9. The computer investment price index employed in the National Income and Product Accounts swung from falling at an average annual rate of 10.6 percent over the 5-year period ending in 2009Q4 to an average annual rate of 2.3 percent over the 5-year period ending in 2014Q4. Byrne and Pinto (FEDS Notes 2015-03-26) raise questions of bias arising since 2009 in the computer investment price index employed in the National Income and Product Accounts. Return to text

10. These calculations are based on the latest available detailed breakdown from BEA of fixed asset investment by product for computers (retrieved June 26, 2013), which only extends through 2012 and shows nominal investment in computer storage devices accounted for roughly 7 percent of overall computers and peripheral equipment from 2004 to 2012. Return to text

11. See Webb (2011), "Extrapolating the Price to Performance Frontier for Computer System Components: Processing, Storage, Memory, and Network Interface," *The Business Review, Cambridge* 18.1 (2011). Return to text

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