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An Empirical Examination of Patent Hold-Up

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Abstract

A large literature asserts that standard essential patents (SEPs) allow their owners to “hold up” innovation by charging fees that exceed their incremental contribution to a final product. We evaluate two central, interrelated predictions of this SEP hold-up hypothesis: (1) SEP-reliant industries should experience more stagnant quality-adjusted prices than similar non-SEP-reliant industries; and (2) court decisions that reduce the excessive power of SEP holders should accelerate innovation in SEP-reliant industries. We find no empirical support for either prediction. Indeed, SEP-reliant industries have the fastest quality-adjusted price declines in the U.S. economy.

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1. Introduction

Economic theory offers conflicting perspectives on whether “patent hold-up” is slowing American innovation. Based on seminal work by Williamson (1967, 1979), Klein, Crawford, and Alchian (1978), Joskow (1985,1988) and Grossman and Hart (1986), the patent hold-up hypothesis asserts that patent holders charge licensing royalties to manufacturing firms that exceed the true economic contribution of the patented technology, thereby discouraging innovation by manufacturers and hurting consumers. Recent work, including by Shapiro (2001), Swanson and Baumol (2005), Farrell, Hayes, Shapiro and Sullivan (2007), Lemley and Shapiro (2007), Miller (2007) and Kobayashi and Wright (2009), emphasizes that the patent hold-up problem is particularly acute for Standard Essential Patents (SEPs).¹ SEPs are patents on inventions that form the standards essential for the inter-operability of connected systems, such as cell phones, personal computers, televisions, and audio-visual systems. Hold-up might be especially pronounced for SEPs because once manufacturing firms make large investments based on an accepted technological standard, SEP holders can extract the value of their patents being part of that standard, not merely the technical contribution of the patent to the final product. From this perspective, granting too much protection to SEP holders slows innovation.

Other work, however, argues that the proposed remedies to mitigate SEP hold-up, such as ex ante determination of royalty rates at the time a patent is declared standard essential, will result in royalty rates that are too low, thereby reducing the incentives for firms to innovate (Elhauge 2008, Ganglmair, Froeb, and Werden 2012). In a similar vein, Schmalensee (2009) and Sidak (2009) argue that the ex post bargaining position of a monopsonistic collection of manufacturers—especially given their abundant legal resources—is much stronger than the bargaining position of patent holders. This reduces the expected returns to inventions and lowers investment in the costly, risky process of developing and patenting new technologies.

¹ See Egan and Teece (2015) for a comprehensive survey.

These scholarly debates shape policy disputes. Arguing that excessive protection of patent holders slows innovation, President Obama has issued five executive orders that reform the current system of patent review and award. In addition, Congress considered, but ultimately rejected, nine different patent reform bills in 2013-14. The current Congress is focused on two strikingly different bills—one that strengthens patent holder rights, and one that weakens those rights.

In this paper, we contribute to these debates by providing empirical evidence on whether SEP hold-up slows innovation. While an extensive theoretical literature examines the possibilities for SEP hold-up, Gerardin, Layne-Farrar, and Padilla (2008) and Barnett (2014) note that there is very little empirical evidence that SEP hold-up actually occurs, and that such evidence as exists is inconclusive. Although policy analysts, lawyers, and practitioners provide anecdotes about SEP hold-up, we are unaware of previous systematic evaluations of the core predictions emerging from IO-based theories of SEP hold-up.

We assess one of the central empirical implications of the SEP hold-up hypothesis: If SEPs are slowing the rate of innovation, then products that are highly reliant upon SEPs will experience more stagnant quality-adjusted prices than similar products that do not rely heavily on SEPs. That is, if the patenting system empowers SEP holders to negotiate excessive royalty payments and this in turn slows innovation by discouraging investment and market entry, then SEP hold-up will harm downstream consumers in the form of slower price declines and slower improvements in product quality and variety. This prediction emerges from a wide assortment of IO-based models of SEP hold-up. Furthermore, this prediction focuses on the essential issue in the policy debate: Are SEPs impeding improvements in consumer welfare by slowing reductions in quality adjusted prices?

To conduct our analyses, we use quality-adjusted price data on a variety of consumer and producer products. Most of our analyses cover the period between 1997 and 2013. We also examine the period from 1951 through 2013 for a smaller cross-section of products due to data availability. We primarily use Consumer Price Series (CPS) from the Bureau of Labor Statistics

(BLS). They provide quality-adjusted price data that reflects the prices paid by consumers, not the prices paid by intermediate producers. However, when firms primarily purchase the product (e.g., computers), we use the Producer Price Series from the Bureau of Economic Analysis (BEA), which also provides quality-adjusted prices. We describe these quality adjustments in Appendix A.

To assess whether SEP hold-up slows innovation, we use two methods. First, we examine the evolution of the quality-adjusted prices of different industries. We differentiate industries by the degree to which their products rely on SEPs. We compare the quality-adjusted price dynamics of SEP-reliant industries, non-SEP-reliant industries, and a textbook hold-up industry: electricity distribution.

We categorize SEP-reliant and non-SEP-reliant industries as follows. A rich literature emphasizes that the personal computer, smart phone, audio and video equipment, and TV industries rely heavily on SEPs.² These are all industries that require interoperability and thus have formal organizations that meet regularly to agree on industry-wide standards. Firms that own patents that read on these standards may then declare their patents as standard essential. Consequently, we categorize products as being SEP-reliant if they are meant to operate as part of a connected system and if there are one or more formal organizations that set technical standards for interoperability in that system. Smartphones provide a classic example: they must not only be interoperable across a variety of different manufacturers and phone service providers, but the photos and video they produce must be compatible with a variety of other products, such as personal computers and video monitors, while their internet capabilities must be compatible with

² For example, Lemley and Shapiro (2007: 1992) state that: “In the information technology sector in particular, modern products such as microprocessors, cell phones, or memory devices can easily be covered by dozens or even hundreds of different patents. As a striking example, literally thousands of patents have been identified as essential to the proposed new standards for 3G cellular telephone systems.” Their case studies (2025-29) focus on 3G cellular technologies, Wi-Fi 802.11 technologies, DVD media, the MP3 music format, and RFID chips. Farrell, Hayes, Shapiro, and Sullivan (2007) also call attention to the potential problem in IT industries. They motivate their paper with seven cases: three of which are about computer technologies, two of which are about modems, and one of which is about cell phones. Swanson and Baumol (2005) point to “computers, software, telecommunications, consumer electronics, and the Internet...” Miller (2007) argues that standard setting organization pervade the information and communication technology industries.

the technical capabilities of various WiFi routers. Standards for smartphones are established by the 3rd Generation Partnership Project (3GPP), which includes a wide variety of network providers, phone manufacturers, component producers, and chip design firms.

We compare these SEP-reliant products against a set of industries whose products have high patent counts, but whose core functions do not require interoperability or compatibility—and therefore do not rely heavily on SEPs. Automobiles provide a classic example: there are SEPs in non-core functions such as Tire Pressure Monitoring Systems, or Rear Set Entertainment Systems, but core functions—most particularly the drive train—are self-contained and thus are proprietary across manufacturers. Table 1 presents summary information about each of the products included in each category: SEP-reliant industries, Non-SEP-reliant industries, and a classic hold-up industry.

The second method for assessing whether SEP hold-up slows innovation involves a quasi-natural experiment in which we evaluate whether a Supreme Court decision that weakened the power of SEP holders accelerated the rate of quality-adjusted price reductions in SEP-reliant industries relative to other industries. The 2006 Supreme Court’s *eBay Inc. v. MercExchange LLC* decision made it more difficult for SEP owners to obtain injunctions against infringers than the holders of non-SEP patents.³ Critically for our analyses, proponents of the SEP hold-up hypothesis advocate for limiting injunctions by SEP holders (Lemley and Shapiro, 2007). They argue that such limits would spur innovation by reducing the excessive power of SEP holders. We examine the impact of this “eBay treatment” effect. Specifically, we employ a difference-in-differences specification and test whether quality-adjusted prices fall faster in SEP-reliant industries after the *eBay Case*, while controlling for industry and year effects. That is, if hold up had been slowing innovation in SEP-reliant industries prior to *eBay*, then we should see a more

³ There is a broad consensus in the legal literature that the firms that license their patents, which by definition includes the holders of SEPs, face greater difficulty in meeting the Supreme Court’s “four-factor test” for a permanent injunction. See Balganes (2008), Beckerman-Rodau (2007), Ellis, Jarosz, Chapman and Oliver (2007), Diessel (2007), Hand (2007), Golden (2007), Grab (2006), Jones (2007), Klar (2006, 2008), Mersino (2007), Mulder (2007), Newcombe, Ostro, King and Ruben (2008), Reis (2008); Rendleman (2008), Solomon (2010), Stockwell (2006), and Tang (2006).

rapid decrease in the quality-adjusted prices of SEP-reliant products relative to non-SEP-reliant products after *eBay*.

In examining the dynamics of quality-adjusted prices, we do not find support for the SEP hold-up hypothesis. We find that products that are SEP-reliant have experienced rapid and sustained price declines over the past 16 years. In contrast, the quality-adjusted prices of a classic holdup industry—electricity distribution—*increased*. The differences in the movement of the quality-adjusted prices of electricity distribution and SEP-reliant products have to be expressed as orders of magnitude. The prices of SEP-reliant products have fallen at rates that are not only fast relative to a classic hold-up industry, they are fast relative to the patent-intensive products that are not SEP-reliant.

Two interrelated concerns are that SEP-reliant products might be more innovative than non-SEP-reliant products for technological reasons and the rate of innovation of SEP-reliant products would have been still faster if SEP hold-up were not slowing innovation. We address these concerns formally when we conduct the quasi-natural experiment based on the *eBay case*. We can address these concerns informally by examining only digital technologies that follow “Moore’s Law.”⁴ If the SEP Hold-up hypothesis holds, we would find that the quality-adjusted prices of Moore’s Law products that are non-SEP-reliant would fall faster than the quality-adjusted prices of products that are SEP-reliant. The data indicate the opposite, however: the prices of non-SEP-reliant Moore’s Law products fall more slowly than the prices of SEP-reliant Moore’s Law products. While illustrative, these graphs do not fully address the concern: among Moore’s Law products, those that rely on SEPs might be more technologically dynamic than other such products. Thus, we examine the differential impact of the *eBay case* on SEP-reliant and non-SEP-reliant industries.

In examining the quasi-natural experiment involving the *eBay case*, we also cannot reject the null hypothesis of no SEP hold-up. The difference-in-differences results do not indicate that

⁴ Moore's Law is the observation that the number of transistors in a dense integrated circuit doubles approximately every two years.

quality-adjusted prices fall faster in SEP-reliant industries after the *eBay Case*. We use several specifications and try de-trending the data to control for potential differences in underlying innovation rates by product. But, in contrast to the SEP hold-up view, we cannot reject the null hypothesis that the *eBay case* did not differentially affect SEP-reliant industries.

It is important to emphasize that we are not claiming that the patent system as currently defined cannot be improved. Rather, we offer evidence on two interrelated predictions of the SEP hold-up hypothesis. First, if SEPs are holding up innovation, then products that are highly reliant upon SEPs should experience more stagnant quality-adjusted prices than similar non-SEP-reliant products. Second, if SEPs are holding-up innovation, then changes in the legal system (the *eBay Case*) that weaken the excessive negotiating strength of SEP holders should accelerate reductions in quality-adjusted prices in SEP-reliant industries relative to non-SEP-reliant industries. We find no evidence for either prediction.

The remainder of the paper is organized as follows. Section 2 describes patent hold-up and uses a simple theoretical model to frame its empirical implications. Section 3 evaluates the testable implications by simply graphing the evolution of quality-adjusted prices of the products in different industries. Section 4 assesses whether SEP-reliant industries experienced a decrease in quality-adjusted prices, relative to non-SEP-reliant industries, following the Supreme Court's *eBay* decision. Section 5 concludes.

2. Holdup and Its Testable Implications

2.1 Patent Hold-Up

The term “hold-up” describes the following situation. Firm A makes a large investment that is specific to an input produced by Firm B and difficult to redeploy to some other use. Firm A contracts with Firm B for the crucial input, but no contract is ever complete and there are always unforeseen contingencies. Thus, after Firm A has made its asset-specific investment,

strategically-timed claims by Firm B allow it to engage in ex post opportunistic negotiation. Oliver Williamson (1985, p. 47) famously described this situation as “self-interest seeking with guile.” Firm A is not a sheep to be fleeced, however; it knows that Firm B can behave opportunistically, and it therefore behaves in ways that protects itself, but that may increase costs, lower output, or slow the rate of innovation.

The quintessential example of hold-up is a mine located in a mountainous area accessible by a single pass. The miner sinks a huge investment in purchasing the subsoil rights, digging and reinforcing shafts and adits, purchasing specialized equipment, and the like—during which time the owner of the pass assures the miner of a reasonable toll for a right of way to get the ore to a distant processing plant. Once the miner has started to produce ore, however, and now faces large sunk costs, the owner of the pass demands a new, higher, toll by exploiting an incomplete element of the initial contract, such as differences in the size or weight of the trucks being used, changes in the construction costs for necessary improvements to the roadway, or any number of similar “problems” that were not originally foreseen. Her new toll rates allow her to extract all of the quasi-rents of the mine, leaving the miner only enough income to cover her variable costs of production.

Knowing that this might happen, the mine owner either makes no investment in the mine in the first place, or invests in the mine in an inefficient fashion, resulting in less mining output at a higher cost of production than would occur otherwise. The result is an increase in the miner’s fixed and average costs, which imply that the mine owner must receive a higher price for her minerals than would be the case otherwise. This scenario is played out across the mining

industry, resulting in higher costs of production in the short run and less entry, competition, and incentives to innovate over the long run.⁵

SEP hold-up is a variety of this general hold-up problem. Instead of a land owner levying an excessive toll for a right of way, SEP hold-up takes place by an SEP holder erecting her own version of a toll booth—a licensing fee for the use of her patent in excess of its “true economic contribution” to a manufactured product. As defined by the Federal Trade Commission (2011, p. 191), ““Hold-up” is [...] a patentee’s ability to extract a higher licensing fee after an accused infringer has sunk costs into implementing the patented technology than the patentee could have obtained at the time of design decisions, when the patented technology competed with alternatives.” Since complex products involve hundreds, if not thousands, of SEPs, and because SEP holders do not know the royalties charged by one another, the SEP hold-up hypothesis implies that SEP holders may jointly extract most, if not all, of the quasi-rents of the manufacturing company via multiple “toll booths”—a theoretical construct known as “royalty stacking.”

2.2 Implications of Patent Hold-Up

The extraction of the manufacturing firm’s quasi-rents by the SEP holder (or holders) has at least four negative implications for the prices paid by consumers and the rate of innovation. First, the manufacturer might respond by accepting the demands of SEP holders, and then pass on the additional costs to consumers, resulting in higher prices than would obtain otherwise.

⁵ The mine owner could respond by investing in lobbying in order to change the contracting environment, by, for example, getting the government to decree that miners can set toll rates ex ante for rights of way on other people’s land—but this option requires the miner to share some of the quasi rents with politicians, again driving up both fixed and average costs, with an attendant drop in output and/or increase in price. During the Porfirio Díaz dictatorship in Mexico (1877-1911) miners successfully lobbied for such a property rights system; landowners were only entitled to price their land in its normal use (not as a right of way), and landowners could be forced to accept the miner’s offer by a government agent via mandatory arbitration. For an analysis of that system, and its attendant political costs, see Haber, Razo, and Maurer (2003, ch. 7).

Second, the manufacturer might respond by investing inefficiently. She might, for example, employ an outdated technology in her product in order to avoid paying the excessive royalties, with a concomitant lack of improvement in product quality. Third, she might vertically integrate by purchasing all of the necessary SEPs—but that would allow the SEP holders to capitalize the quasi-rents they extract via royalties into the market price of their patents, thereby driving up the manufacturer's fixed and average costs. The manufacturer must either accept lower profit margins, with concomitant reductions in R&D spending for future rounds of innovation, or pass these additional costs on to consumers. Fourth, the manufacturer might infringe the SEP holders' patents, forcing them into expensive litigation, the cost of which will either be passed on to consumers or be absorbed by profit margins, hence reducing the R&D budgets for future rounds of innovation. These tough choices are then played out across the entire industry of which this manufacturer is a part, raising costs in the short run, and reducing market entry, competition, and the incentives to innovate in the long run.

In short, the equilibrium outcome of the SEP hold-up hypothesis is that consumers either face higher prices or lower quality products than they would if hold-up was not taking place. This yields the core testable hypotheses discussed in the Introduction:

(1) If SEPs are holding up innovation, then products that are highly reliant upon SEPs should experience more stagnant quality-adjusted prices than similar non-SEP-reliant products.

(2) If SEPs are holding up innovation, then changes in the legal or regulatory system that reduce the excessive power of SEP holders should accelerate reductions in quality-adjusted prices.

2.3 SEP Hold-Up and Quality-Adjusted Prices: A Model

In this subsection, we use a simple model to illustrate the impact of SEP hold-up on quality-adjusted prices. The model shows that under quite general conditions, factors that slow the rate of innovation will slow the rate of decline of the quality-adjusted price. The thrust of the result is as follows. Take two industries, A and B, and suppose that A's productivity and quality grow one percentage point faster than in B. Then, A's quality-adjusted relative price falls one percentage point faster than B's.

2.3.1 A simple model

Production Let

$$Y_i = \varphi_i A_i L_i^{\alpha_i} K_i^{1-\alpha_i}$$

be the aggregate Cobb-Douglas production function of industry i . Y is output, and L and K are labor and capital respectively; A is the standard total factor productivity parameter, and φ is a quality parameter.

Goods markets The inverse nominal demand for good i is P_i and

$$\eta_i \equiv -\frac{P_i}{Y_i P_i'}$$

is the elasticity of demand. Let c_i be the (constant) nominal marginal and average cost of producing good i , and p_i represents its nominal price. Then we assume that in equilibrium

$$\frac{p_i - c_i}{p_i} = \frac{\theta_i}{\eta_i}, \quad (1)$$

where θ_i is a conduct parameter which summarizes the outcome of competition among firms in

industry i . It is equal to one under monopoly, zero under perfect competition and equal to $1/n$ in a symmetric Cournot model with n firms. More generally, it nests most oligopoly models and summarizes the intensity of competition.⁶

Simple manipulation of (1) yields

$$p_i = \left(\frac{\eta_i}{\eta_i - \theta_i} \right) c_i \equiv m_i c_i$$

Thus the margin, m_i , measures markup over costs—a standard measure of market power.

Factor demands We assume perfectly competitive factor markets. Let w be the nominal wage r the nominal rental price of capital. Then profit maximization implies that K_i and L_i solve

$$\max_{L_i, K_i} \left\{ P_i(Y_i) \varphi_i A_i L_i^{\alpha_i} K_i^{1-\alpha_i} - rK_i - wL_i \right\}.$$

Now let y_{L_i} be the marginal product of labor in sector i and y_{K_i} the marginal product of capital.

First order conditions imply that value marginal revenue products equal factor prices, viz.

$$w = \frac{p_i}{m_i} y_{L_i} \equiv \frac{p_i}{m_i} \alpha_i \varphi_i A_i \left(\frac{K_i}{L_i} \right)^{1-\alpha_i}, \quad (2)$$

and

$$r = \frac{p_i}{m_i} y_{K_i} \equiv \frac{p_i}{m_i} (1-\alpha_i) \varphi_i A_i \left(\frac{L_i}{K_i} \right)^{\alpha_i}, \quad (3)$$

⁶ We follow Genesove and Mullin's (1998) variation on Bresnahan (1989).

2.3.2 Some results

Define $\hat{x} \equiv d \ln x$. Total differentiation of (2) and (3) and some simple manipulation yield

$$\begin{aligned}\hat{p}_i &= \hat{w} + \hat{m}_i - \hat{y}_{L_i} \\ &= \hat{w} + \hat{m}_i - (\hat{A}_i + \hat{\phi}_i) - (1 - \alpha_i)(\hat{K}_i - \hat{L}_i)\end{aligned}\quad (4)$$

and

$$\begin{aligned}\hat{p}_i &= \hat{r} + \hat{m}_i - \hat{y}_{L_i} \\ &= \hat{r} + \hat{m}_i - (\hat{A}_i + \hat{\phi}_i) - \alpha_i(\hat{L}_i - \hat{K}_i)\end{aligned}\quad (5)$$

The first line in (4) and (5) says that industry's i nominal price increases with nominal factor prices and market power but falls with factor productivity growth. The second line decomposes the change in factor productivity. Note that the nominal price of industry i falls one-for-one with $(\hat{A}_i + \hat{\phi}_i)$, the sum of total factor productivity increases and quality improvements. That is, innovation directly influences prices.

Now it is easy to show that

$$\hat{y}_{L_i} - \hat{y}_{K_i} = \hat{K}_i - \hat{L}_i = \hat{w} - \hat{r}, \quad (6)$$

The first equality says that in equilibrium, differences in factor productivity growth reflect changes in factor proportions. The second equality links changes in factor proportions with changes in relative factor prices. Substituting (6) into (4) or (5) and rearranging yields

$$\hat{p}_i = -(\hat{A}_i + \hat{\phi}_i) + \alpha_i \hat{w} + (1 - \alpha_i) \hat{r} + \hat{m}_i. \quad (7)$$

Thus industry's i quality-adjusted nominal price falls one-by-one with increases in total factor productivity and quality growth, and rises with increases in factor prices and market power.

2.3.3. The differential rate of innovation and the rate of change of relative prices

Let p be a price index such that

$$p \equiv \prod_i (p_i)^{\lambda_i}, \quad (8)$$

where λ_i is the share of industry i in the index, and $\sum_i \lambda_i = 1$. Then p_i / p is industry's i relative price and $\hat{p}_i - \hat{p}$ is the rate of change of i 's relative price. Now substituting (7) into (8), taking logs and differentiating yields

$$\begin{aligned} \hat{p} &\equiv \sum_{i=1}^n \lambda_i \left[-(\hat{A}_i + \hat{\phi}_i) + \alpha_i \hat{w} + (1 - \alpha_i) \hat{r} + \hat{m}_i \right] \\ &\equiv -(\hat{A} + \hat{\phi}) + \bar{\alpha} \hat{w} + (1 - \bar{\alpha}) \hat{r} + \hat{m}, \end{aligned}$$

which is the rate of change of the price index. Thus the price index varies inversely and one-by-one with average total factor productivity and quality growth. The change in its relative price is thus

$$\begin{aligned} \hat{p}_i - \hat{p} &= -\left[(\hat{A}_i + \hat{\phi}_i) - (\hat{A} + \hat{\phi}) \right] + (\alpha_i - \bar{\alpha}) \hat{w} + (1 - \alpha_i - \overline{1 - \alpha}) \hat{r} + (\hat{m}_i - \hat{m}) \\ &\equiv -\left[(\hat{A}_i + \hat{\phi}_i) - (\hat{A} + \hat{\phi}) \right] + \varepsilon_i \end{aligned} \quad (9)$$

with $\sum_{i=1}^n \varepsilon_i = 0$ by construction.

Expression (9) says that in equilibrium, the rate of change of industry i 's relative price equals the inverse of industry's i differential rate of productivity and quality growth, $(\hat{A}_i + \hat{\phi}_i) - (\hat{A} + \hat{\phi})$, up to a mean-zero error term. In other words, fast relative price declines are strong indicators of differences in the rates of innovation.

Similarly, the relative growth rate of prices,

$$\hat{p}_i - \hat{p}_j = (\hat{A}_i + \hat{\phi}_i) - (\hat{A}_j + \hat{\phi}_j) + (\varepsilon_i - \varepsilon_j),$$

reflects the differential rate of productivity and quality growth. Hence, if productivity and quality

in X grow one percentage point faster than in Y, then X's quality adjusted relative price should fall one percentage point faster than Y's on average.

Indeed, empirical studies show that there is virtually a one-to-one relationship between relative price changes and differential rates of productivity growth across industries. Salter (1960) found this when he examined the differential productivity performance of 28 British manufacturing industries between 1924 and 1950, as well as the differential productivity performance of 27 U.S. industries between 1923 and 1950. Oulton and O'Mahoney (1994) replicated this result by studying 136 manufacturing industries in Britain between 1953 and 1986. Kendrick and Grossman (1980) looked at the entire U.S. economy (20 manufacturing industries, plus agriculture, public utilities, construction, and several service industries) and found a coefficient that was similar to that in Salter (1960). Nordhaus (2008) extended Kendrick and Grossman's (1980) data to 2001, with similar results.

2.3.4. Relative price change and the hold-up hypothesis: observable implications

The hold-up hypothesis argues that hold-up will slow innovation. It follows that hold-up should lead to a slower rate of decline $(\hat{A}_i + \hat{\phi}_i) - (\hat{A} + \hat{\phi})$ of the quality-adjusted relative price. Hence, if hold-up is materially reducing the rate of innovation in SEP industries, the relative price of SEP goods should be stagnant relative to all other goods and to goods that exhibit fast rates of innovation but no holdup problem (e.g. those that benefit from Moore's law but are not SEP-reliant).

Second, if SEPs are holding up innovation, then changes in the legal system (the eBay Case) that reduce the power SEP holders should accelerate reductions in quality-adjusted prices.

3. Empirical Analyses: The Evolution of Quality-Adjusted Prices

In this section, we examine the implications of the SEP hold-up hypothesis regarding the movement of the quality-adjusted prices of SEP-reliant products relative to that of other products.

3.1 Categorizing Industries

SEPs have become particularly common over the past two decades in the production and operation of digital electronic products—e.g., personal computers, phones, televisions, and audio systems. The reason is that these products must be inter-operable and compatible; they are connected systems. The owner of Smartphone A must be able to talk with, and share pictures, video, and other media with the owner of Smartphone B—even though A and B are made by different manufacturers and operate on networks owned by different companies. The owner of Smartphones A and B must also be able to transfer that media to laptops C and D, and those laptops must be able to project the audio and video on televisions E and F, as well as burn them onto disks that can be played on DVD players G and H. The numerous technical problems created by the requirements of this connected system are solved by standard setting organizations (SSO's), which include upstream component manufacturers and downstream device manufacturers, as well as firms that operate the networks that link devices together. Owners of patents that read on the technical standards established by the SSO can then declare those patents as standard essential, and the SEP owner and a user of that SEP can then negotiate a royalty for its use. We therefore follow the SEP hold-up literature, by categorizing as SEP-reliant those products whose core functions require inter-operability and compatibility, and which also have at least one formal organization that sets technical standards for that industry. We categorize products that embody patents, but that do not meet this two-fold test, as non-SEP-reliant. We

note that none of the products we place in the non-SEP-reliant category is mentioned in the SEP hold-up literature. Table 1 summarizes the information about the products in both categories.⁷

One potential concern with our examination is that SEP-reliant products tend to cluster in digital electronics, and those products might have inherently different rates of innovation than non-digital products that are non-SEP reliant. Fortunately, there are digital products that do not require high degrees of inter-operability and compatibility, such as watches, coin operated gaming machines, electrical test equipment, and multi-user (e.g., mainframe) computers. Quality-adjusted price data on these products therefore provides us with a second source of analytic leverage. When we turn to the difference-in-differences estimation in Section 4, we further control for inherent differences in rates of innovation across industries by de-trending each product's quality-adjusted price data.

As a benchmark, we use the evolution of the quality-adjusted long-run price data for a product that is a textbook case of hold-up, retail electricity. Retail electricity production has three stages: generation, high-voltage transmission, and low voltage distribution. Two of those stages, transmission and distribution are natural monopolies. Because the assets in each of these stages are site-specific, sunk for decades, and electrons, once produced, cannot be stored efficiently, electricity is particularly susceptible to ex-post contractual opportunism. For example, the generating companies, which tend to be located far from major consumption sites (large industrial users and cities), can be held up by the transmission companies that transport the power. What is to stop the transmission company from offering a lower price per kilowatt-hour by claiming that some circumstance has changed in an unexpected fashion? Similarly, what is to stop the generating company from reducing output, thereby holding up the transmission

⁷ We checked our categorizations with expert practitioners. We are grateful to Lew Zaretzki of Hamilton IPV for guidance on the various standards and SSOs governing the products covered in this paper.

company and the distribution company for a higher price per kilowatt-hour when they need a rapid increase in power, say, on a hot day when demand for air conditioning skyrockets? The same problems of ex-post contractual opportunism plague the relationship between the transmission company and the distributors to households and business enterprises. What is to keep the transmission company from demanding higher prices from distributors when demand spikes?

Historically, many electricity systems were initially built and operated by unregulated private firms. High prices and coordination failures among generators, transmission companies, and distributors were pervasive (Gilbert and Khan 1996). Eventually, these problems were “solved” by the creation of vertically integrated regulated monopolies (in the United States) or state-owned firms (in Western Europe)—none of which were known for their innovativeness.

In order to spur efficiency and innovation, in recent decades governments around the world unbundled these vertically integrated monopolies and privatized them. What now tends to exist are independent and regulated monopolies in transmission and distribution, but multiple firms in generation. The fundamental problem of transmitting and distributing a product that cannot be stored and that is characterized by scale economies remains, however. Thus, the electricity industry is still characterized by hold-up and the potential for the exercise of market power, which governments have tried to prevent by regulating competition and the bidding process in markets for wholesale power. The results have been mixed at best and the possibilities for opportunistic behavior are numerous. For example, Enron’s energy traders were able to encourage electricity generating companies in California in the early 2000s to reduce the supply of power during times of peak demand in order to “perform maintenance,” producing both “rolling blackouts” and exponential increases in the prices charged to energy distribution

companies. It is unsurprising that technological progress in the electricity industry has been slow: the last major breakthrough in generation technology was the introduction of combined-cycle gas generation in 1965; most homes and businesses still use a Shallenberger induction meter, invented in 1888; and the digital revolution has yet to reach energy management and use within homes, businesses, and public buildings.

Figure 1 shows the real (inflation adjusted) price of electricity for urban consumers in the United States from 1997 to 2013, and compares those prices against the quality-adjusted, real prices of seven SEP-reliant products; telephone equipment, televisions, portable / laptop computers, desktop computers, video equipment, audio equipment, and photographic equipment. All series are converted to a base year of 100, so as to make price movements relative to each other. We discuss the sources for each series in Appendix A. The data show that the price of electricity has barely moved over those 16 years, which is exactly what one would expect of a hold-up industry characterized by slow rates of innovation.

3.2 Do relative prices of patent-intensive SEP industries stagnate?

The contrast between the behavior of the relative price of products that are SEP-reliant and the price of electricity is stark. Even the product with the slowest decline in quality-adjusted relative prices, audio equipment, fell by 7 percent per year—a striking result considering that the maximum rate of long-run productivity growth for an industry is typically less than 6 percent per annum. The quality-adjusted relative price of telephone equipment fell 10 percent per annum. By 2013, the price of a phone, taking into account inflation, changes in the prices of phones, and improvements in phone technology, was 79 percent lower than in 1997. If you ever wonder why you see a massive, flat-screen television just about everywhere you look, consider the

following fact: between 1997 and 2013, the relative, quality-adjusted price of TVs fell by 19 percent per year. The relative quality-adjusted price of portable and laptop computers fell fastest of all, by 31 percent per annum.

Figure 2 graphs the average of the quality-adjusted relative prices of the seven SEP-reliant products displayed in Figure 1 and compares them to another complex product of wide use, automobiles. Automobiles employ thousands of patents, but their core functions are non-interoperable and non-compatible: the drive trains of Porsches and Hondas are separate closed systems. Figure 2 reveals that on average, the relative, quality-adjusted price of SEP-reliant electronic products—the same goods that the literature claims to be subject to SEP Hold-up—fell by 14 percent per year. The contrast with automobiles is unambiguous: the quality-adjusted relative price of new cars fell by less than 3 percent per year between 1997 and 2013, roughly five times slower than SEP-reliant products.

These figures indicate that SEP-reliant industries do not stagnate relative to patent-intensive, non-SEP-reliant industries. These figures do not, however, address the possibility that patent-intensive SEP-reliant industries were—for technological reasons—more technology dynamic than other industries. If this is were the case, then the figures would not rule out the possibility that the rate of innovation in patent-intensive SEP-reliant industries would have been still faster if SEP hold-up were not slowing down the rate of innovation in SEP-reliant products. We address this potential concern in two ways. First, we focus only on digital technologies that follow “Moore’s Law” and hence restrict our analysis to digital products that differ only in their reliance on SEPs. Second, we address this more formally by conducting a quasi-natural experiment based on the *eBay case*.

3.3 “Moore’s Law” Digital Products

Perhaps, there are fundamental differences between digital electronic products and automobiles such that one would not expect them to display the same rates of innovation. Perhaps, the SEP-reliant, digital electronic products graphed in Figure 1 are all subject to “Moore’s Law” (the observation that the number of transistors in a dense integrated circuit doubles approximately every two years), and hence—for technological reasons having nothing to do with the patent system—experience much faster rates of innovation than other products.

We can both address and exploit this “Moore’s Law Critique.” In terms of addressing it, there are two points. First, if the rate of innovation in digital electronic products is only dictated by some inherent characteristic of the underlying technology, then the entire debate about SEP hold-up is beside the point. The pace of technology is moving so fast that SEPs are irrelevant; today’s “standard” is tomorrow’s museum piece. Second, Moore’s Law is not a law of nature, like the speed of light, but is a rule of thumb about an empirical regularity in a particular institutional context. An historical case illustrates the point. In 1984 Brazil tried to catch up in personal computer technology through infant industry protection and other supports to its IT sector, and the result was disastrous: there was no Brazilian version of “Moore’s Law,” just lots of high priced, badly-made, slow clock speed PCs. The implication is that the empirical regularity called “Moore’s Law” is observed in the United States because the institutions that govern the specification of intellectual property rights here is conducive to very fast rates of innovation.

More importantly, we can exploit the “Moore’s Law” critique by comparing the rate of innovation across a variety of products that all employ densely packed integrated circuits, but which vary in the intensity with which they employ SEPs because they require different levels of

inter-operability and compatibility. For example, DVD player X must be able to play all the same music and video as DVD player Y—and both must be able to project images on televisions C and D, or load software onto personal computers E and F. This high degree of inter-operability and compatibility is, however, much less important in products such as digital watches, digital gaming machines, or multi-user computers. Digital watch A and digital watch B do not have to communicate with each other or any other device. Mainframe computers are constructed to run customized software on proprietary architectures. Thus, we ask whether digital products that make intensive use of SEPs demonstrate slower rates of innovation, as measured by quality adjusted relative prices, than digital products that make less intensive use of SEPs.

Figure 3 therefore presents data on the quality adjusted, relative prices of digital watches, test equipment for electrical radio, and communication circuits, and coin operated gaming machines against the average of the seven SEP-reliant products analyzed in Table 1. There are big differences in the series: the SEP-reliant products demonstrate differential rates of innovation between two and four times faster than less SEP-reliant digital products. In fact, even if we look at the SEP-reliant digital product with the slowest rate of innovation (audio equipment, whose quality adjusted relative price fell at a rate of seven percent per year), we still find that its rate of innovation is more than twice as fast as any of the three non-SEP-reliant products.

We can push this a bit further, since it might be the case that SEP-reliant products have greater innovation possibilities than digital products that are not SEP-reliant. For example, there might be fundamental differences between audio equipment and watches. Therefore, in Figure 4, we compare the quality adjusted relative prices of three products that perform similar functions using similar underlying technologies—but two (desktop and laptop computers) are SEP-reliant,

while the third (multi-user computers, which includes mainframes, Unix computers and PC servers) is much less SEP-reliant. If the SEP hold-up hypothesis holds, we should expect to see slower rates of innovation in desktops and laptops than their more powerful, specific purpose cousins. Due to data availability, these analyses cover the period from 2004 through 2013. As Figure 4 demonstrates, however, we see exactly the opposite. In fact, laptops and desktops illustrate rates of innovation almost twice that of multi-user computers, with average annual quality adjusted price declines of 26 percent, 25 percent, and 14 percent per year respectively.

3.4 Taking a Longer-Run View of the Data

So far, we have restricted the analyses to the post-1996 period to have the broadest possible coverage of products. What happens if take an even longer time span to look at the data on a smaller number of products?

Figure 5 therefore compares the quality adjusted relative prices of electricity, telephone equipment, televisions, and an index of video, audio, photographic, and information processing equipment from 1951 to 2013 (with 1951 equal to 100 for all series, so as to make price movements relative to each other).⁸ The relative price of electricity declined only slightly over this six-decade period, which is exactly what one would expect of an industry characterized by hold-up. The quality adjusted relative price of televisions, however, fell like a stone. By 2013, the price of a television (taking into account inflation, price changes, and improvements in quality) was less than one percent of what it had been in 1951. The same is true for the index of video, audio, photographic, and information processing equipment.

⁸ Video (other than televisions), audio, photographic, and information processing equipment were grouped together by the BLS prior to the 1990s.

Telephone equipment displays an interesting pattern, one that allows us to get analytic leverage on what happens when a product changes from being produced by a vertically-integrated monopoly to a SEP-reliant industry. Until 1982, local telephone services in the United States were provided by a single company, ATT, which leased telephones made by its Western Electric subsidiary to businesses and households. Until the FCC's 1968 Carterphone Decision, equipment produced by other manufacturers could not be operated on ATT's network. Not surprisingly, the quality adjusted, relative price of phone equipment barely moved at all. Once business enterprises and households began to purchase equipment made by other manufacturers in the 1970s, the quality adjusted relative prices of phone equipment began to fall gradually. Between 1970 and 1980, the price of a phone, adjusting for inflation and quality, fell by 14 percent.

This pattern reversed in the 1980s when the first mobile phones—all produced by a single manufacturer, Motorola—entered the U.S. market. Motorola's initial product, the DynaTAC 8000X, had a price of \$3,995 (about \$9,000 in today's dollars), weighed more than a kilo, and had a battery life of half an hour. The quality adjusted relative prices of phones continued to climb until 1997, by which point there were multiple manufacturers of 2G cell phones competing for market share. From that point onwards, through both the 3G and 4G revolutions, the quality-adjusted price of telephone equipment fell by ten percent per year.

Note that the trajectory of the relative price of telephone equipment is the opposite of what the patent hold-up hypothesis would predict. As long as telephone equipment was produced by a subsidiary of ATT, and thus by definition could not have been subject to hold-up, its relative price remained constant. Once the cell phone diffused in the late 1990s, however, and

telephone equipment became the quintessential SEP industry, prices plummeted, the opposite prediction of the SEP hold-up hypothesis.

While illustrative, these figures do not fully address the concern that technologies that rely on standards are technologically more dynamic. Thus, next we study the differential effect of the *eBay case* on SEP-reliant and non-SEP-reliant industries.

4. Empirical Analyses: The *eBay Case* as a Quasi-Natural Experiment

One argument made in the SEP hold-up literature is that the ability to obtain injunctions against manufacturers allows SEP owners to extract royalties above their “true economic contribution.” In 2006, however, the Supreme Court decision in *eBay Inc. v. MercExchange LLC* made it relatively more difficult for SEP owners to obtain injunctions against infringers.⁹ The eBay decision therefore allows us to leverage variance across time as well as variance across products. If hold-up was taking place in the manufacture of products that were highly reliant on SEPs prior to *eBay*, after *eBay* we should see a more rapid decrease in the quality-adjusted prices of those products, relative to the quality-adjusted prices of products that are non-SEP-reliant. If we fail to detect that more rapid decrease, it implies that hold-up was not slowing the rate of innovation prior to the eBay decision.

We use the following difference-in-differences structure to assess whether *eBay* spurred the relative rate of innovation in SEP-reliant industries:

$$P_{i,t} = \alpha + \beta[\text{SEP}_i \times \text{Post2006}_t] + \gamma \text{SEP}_i + \delta_i + \delta_t + \varepsilon_{i,t}, \quad (10)$$

⁹ As numerous legal scholars have pointed out, the eBay decision has made it more difficult for a firm that licenses its patents rather than practices them to meet the “four-fold test” for an injunction, particularly the ability to demonstrate “irreparable injury” from infringement. See Balganes (2008), Beckerman-Rodau (2007), Ellis, Jarosz, Chapman and Oliver (2007), Diessel (2007), Hand (2007), Golden (2007), Grab (2006), Jones (2007), Klar (2006, 2008), Mersino (2007), Mulder (2007), Newcombe, Ostro, King and Ruben (2008), Reis (2008); Rendleman (2008), Solomon (2010), Stockwell (2006), and Tang (2006).

where $P_{i,t}$ is the quality-adjusted price of products in industry i in year t , SEP_i is a dummy variable that equals one if industry i is a SEP-reliant industry and zero otherwise, $Post2006_t$ is a dummy variable that equals zero until 2006 and one from 2007 onward, and δ_i and δ_t represent the fixed effects on industry and year dummy variables. If β enters negatively and significantly, then this would be consistent with the view that the *eBay Case* spurred the comparative rate of innovation in SEP-reliant industries. If the regression analyses do not reject the hypothesis that $\beta=0$, then we the data would not reject the null hypothesis that the eBay Case did not influence the relative rate of innovation in SEP-reliant industries. The regression is estimated over the period from 1997 through 2013. We experimented with different ways of clustering the standard errors, including no clustering, clustering at the industry level, and clustering at the year level. We obtain similar results and report the results with no clustering.

Table 2 indicates that the analyses do not reject the null hypothesis that the *eBay Case* did not accelerate the relative rate of innovation in SEP-reliant industries. The eBay decision coefficient on $SEP_i \times Post2006_t$ is positive and insignificant in column (1). In searching to find a specification that is consistent with the SEP hold-up hypothesis, we extend the analyses in two ways. One might think that different products have inherently different potential rates of innovation (i.e., that automobiles cannot be improved as quickly as smartphones). In Column 2, we therefore de-trend the data, by subtracting from each observation that product's pre-2007 average price decline. This did not alter the results. We also extend the analyses by restricting the sample to products that are subject to "Moore's Law." In Column 3, we therefore truncate the data so that the non-SEP-reliant category only includes digital electronic products. Once again, we get a coefficient with the "wrong" sign that is not statistically significant. We also employ a jackknife approach, serially dropping products from the regression, and never obtain a

statistically significant negative coefficient on $SEP_i \times Post2006_i$. In short, we could not reject the null hypothesis that there was no change in the relative rates of innovation in SEP-reliant industries after the *eBay* decision.

5. Conclusions

In this paper, we find that the rate of innovation—as reflected in quality adjusted relative prices—has rarely, if ever, been faster than it is today in exactly those products that scholars agree are theoretically subject to SEP hold-up. We find that prices of SEP-reliant products have fallen at rates that are not just fast compared to a classic hold-up industry, but that are fast against patent-intensive, non-SEP-reliant products. Moreover, when the courts made it harder for SEP holders to hold-up manufacturing firms, we find that this did not accelerate the rate of innovation in SEP-reliant industries relative to other industries. We cannot reject the hypothesis of no SEP hold-up.

One might wonder why there is such a noticeable mismatch between the evidence and theories that articulate how SEP holders can charge royalty rates that capture the value of the standard itself, rather than just their patent's technical contribution to it. We would speculate that markets find ways of ameliorating the adverse effect from patent hold-up. A decentralized system of incomplete contracts involving actors engaged in a repeated game and who coordinate around a focal point in order to expand the boundaries of the market—in this case a standard setting organization—is particularly well suited for facilitating innovation (Egan and Teece, 2015). Indeed, such a diffuse system in which the common interest dominates conflicts of interest describes one of the modern world's most innovative organizations: the American research university.

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Appendix A: CPI Series Definitions and Quality Adjustment Methods¹⁰

In this appendix we describe each price series that we use and mention the method used to adjust for quality. Column references are to the spreadsheet “Basic Data” in the file Consolidated Data Set for Holdup.xlsx which holds the data we use.

Our default source is the BLS’s Consumer Price Series. We prefer this data because it reflects prices paid by consumers, not prices paid by intermediate producers. We only depart from this rule if two conditions are met. First, there is a much longer non-Consumer Price series. Second, the Non-Consumer Price Series and the Consumer Price Series are materially similar for the overlapping years, suggesting that the underlying data is pulled from the same source. In choosing an alternative series (when the CPI has a shorter run of data), we give priority to series from the Bureau of Economic Analysis, Personal Consumption Expenditures by Type of Product, from Table 2.4.4 of the Department of Commerce, Bureau of Economic Analysis (2013).

Electricity; CPI code: CUUR0000SEHF01

ELI¹¹ definition: Data are collected on service charges (a fixed charge per bill); consumption charges (for total monthly energy usage); additional charges and credits; taxes.

The prices for electricity include seasonal changes, such as summer or winter rates. Also included are additional charges and credits, such as purchase fuel adjustments. It also includes electricity service to individually-metered residential units.

Quality adjustment method: Electricity is not quality-adjusted.

¹⁰ Series definitions come from BLS’s internal ELI series definitions. They were retrieved by email from Steve Reed of the CPI office.

¹¹ “The CPI item structure has four levels of classification. The 8 major groups are made up of 70 expenditure classes (ECs), which in turn are divided into 211 item strata. Major groups and ECs do not figure directly in CPI sample selection [...]. Within each item stratum, one or more substrata, called entry-level items (ELIs), are defined. There are a total of 305 ELIs, which are the ultimate sampling units for items as selected by the BLS national office. They represent the level of item definition from which data collectors begin item sampling within each sample outlet.” (Department of Commerce, Bureau of Labor Statistics 2013, ch. 17, p. 13).

Telephone hardware, calculators, and other consumer item; BEA code: DCTERG3

The BEA uses the CPI series for telephone hardware, calculators, and other consumer items (code: CUUR0000SEEE04), which is subdivided into two subcomponents:

Subcomponent (i): Telephones, peripheral equipment, and accessories (ELI: EE041) ELI definition: Home-based and cellular telephones, telephone answering devices, Caller ID units, additional cordless handsets, and accessories. Excluded are home telephone and cellular telephone *services*.

This price series is divided into 3 specification clusters: Cluster 01C: Cellular telephones; Cluster 02B: Home-based telephones; Cluster 03B: Telephone peripheral equipment and accessories.

Subcomponent (ii): Calculators, typewriters, and other information processing equipment (ELI: EE042). ELI definition: Calculators, typewriters, and other information processing equipment for non-business use. ELI excludes equipment referred to as Personal Digital Assistants (PDA's) or handheld PC's. These items are priced in ELI EE011. This ELI is divided into 2 specification clusters: Cluster 01A: Calculators; Cluster 02A – Typewriters and other information processing equipment. The CPI office at the BLS states that this subcomponent price series is primarily comprised of calculators.

Quality adjustment method: The BEA does not adjust the series for quality. However, the CPI does a hedonic quality adjustment.

Televisions CPI code: CUUR0000SERA01

ELI definition: All non-portable, electronic video displays with television tuners. Televisions with built-in DVD or other media players are included. Televisions included in component

systems are eligible as long as there is an individual price for the TV. Televisions including separate speakers or stands are also included.

ELI excludes: Computer monitors (displays without television tuners), and televisions designed for portable viewing (those with battery power) are priced in RA031. Also excluded are television/audio component systems (audio components are priced in RA051) and television/video component systems (video components are priced in RA031).

Quality adjustment method: Quality is adjusted with the hedonic price method since 1999 (Kokoski, Waehrer and Wright (1999)).

Other video equipment –CUUR0000SERA03

ELI definition: Includes purchased hardware used for displaying or making video. Set-top boxes, devices used to stream video between devices (Apple TV, Slingbox, etc.), video cassette recorders (VCRs), digital and personal video recorders (DVR or PVR), video disc players/recorders (DVD or Blu-ray), portable DVD players and other portable video players with screens larger than 7", handheld portable TVs that are designed to operate on batteries, video cameras (camcorders), satellite television equipment, video accessories, and other video products.

ELI excludes: Excludes all stationary televisions including televisions designed to be installed in an automobile. Also excluded are video tapes and discs for sale or rent, rental of video equipment, digital video recorder services, and satellite dish programming services. Portable media players with screens smaller than 7" are excluded unless they include a DVD player. Also excluded are digital/personal video recorder subscription services. Cameras primarily intended for still photography are excluded even if they have a video feature.

Cluster Definitions: This list is divided into four clusters: Cluster 01D - Video Players/Receivers: Devices that obtain video from another source-whether through a telecommunications line such as cable or the internet, or from another home device such as a personal computer-so that the video can be displayed or recorded for display on a television, monitor, or projector. Examples include VCRs, DVD players, cable set-top boxes, DVRs, and Apple TV. Portable video players belong in cluster 02C. Cluster 02C - Portable Video Players: Devices that combine a screen, a video source, and battery power so video can be viewed on the go. Included are DVD players, televisions, satellite TV players, and DVRs designed for portable viewing. Cluster 03C - Video Cameras/Camcorders: Motion photography devices used to record video. Cameras primarily intended for still photography are excluded from this ELI. Cluster 04B - Other Video Products/Accessories: All video products eligible in the ELI that do not fall in one of the above clusters. Examples include video cables, antennas, and television remote controls. Quality adjustment method: The BLS does a hedonic quality adjustment since 2000 (Kokoski, Waehrer and Wright (1999)).

Audio equipment CPI Code: CUUR0000SERA05

ELI definition: All types of home, portable, and automobile audio equipment and accessories.

ELI excludes: Portable media players with screens larger than 7" are excluded (these are priced as video equipment). Personal audio players that can run Apps and browse the internet are priced under handheld computers. DVD, Blu-Ray, video streamers, and all other video players are excluded unless the unit functions primarily as receiver or is part of a bundled "Home Theater System."

This price series is divided into five clusters: Cluster 01B - Personal audio devices: Audio players and recorders designed for mobile use with headphones. Cluster 02B - Audio systems, components, and speakers: Receivers, stereo components and systems, speakers, and home theater systems. Cluster 03B - Automobile audio equipment: Audio equipment designed for installation and use in an automobile. Cluster 04A - Compact audio including boomboxes and docks: Complete audio systems that include built-in speakers including clock radios and docks for personal audio devices. Cluster 05 – Accessories: Headphones, audio cables, and other accessories.

Quality is adjusted using imputation, wherein the BLS estimates the price change between a newly discontinued stereo and the new stereo via the price change of all other comparable stereos in the area. Since 2000, the BLS uses the hedonic price method to adjust quality. (Kokoski et al. (1999).)

Video, audio, photographic, and information processing equipment and media (75, 76, and part of 93) BEA code: DVAPRG3

Quality adjustment method: Quality is adjusted with the hedonic price method since 2000.

Photographic equipment CPI code: CUUR0000SS61023

ELI definition: Digital cameras and lenses intended primarily for still photography. Included in ELI but excluded from pricing: Other photographic equipment (including film cameras, tripods, and camera bags) are included in the ELI but not priced. ELI excludes: in ELI RD011 digital memory cards and readers (included in ELI EE021), office/document printers and scanners

(included in ELI EE011), photo printer paper (included in ELI GE011), photo printer ink cartridges (included in ELI EE021), and digital picture frames (included in ELI HL012)

This price series is divided into two specification clusters: CLUSTER 01C - Fixed lens cameras: Cameras with a built-in lens. These cameras may be referred to as point-and shoot. CLUSTER 02C - SLR, interchangeable lens cameras, and lenses: Cameras designed to work with removable lens including SLRs and mirrorless ILC (interchangeable lens camera). This cluster also includes lenses designed to work with these cameras.

Quality adjustment method: Quality adjusted using imputation, wherein the BLS estimates the price change between a newly discontinued piece of photography equipment and the new piece of photography equipment via the price change of all other comparable photography equipment in the area.

Electronic computers and workstations PPI code: WPU11510114; *Portable Computers, Laptops, PDAs, and other single user Computers* PPI code: WPU11510115; *Portable Computers, Laptops, PDAs, and other single user Computers* PPI code: WPU11510116 (See International Monetary Fund (2004, pp. 261-263)).

Quality adjustment method: Hedonic price method (See Department of Commerce, Bureau of Labor Statistics (2008) and Wasshausen and Moulton (2006)).

Test equipment for electrical, radio, & communication circuits & motors PPI code: WPU11720501

Quality adjustment method: Production cost-based quality adjustment

Coin operated amusement machines PPI code: WPU119308

Includes electronic casino gaming devices, slot machines, juke boxes, arcade games, pinball machines, “wood machines” that could be in an arcade (such as a wooden shuffle board), ticket dispensers, and parts for the aforementioned machines. Excludes games that require a computer, personal gaming devices, or games that could be considered a sport.

Quality adjustment method: Production cost-based quality adjustment

Watches – CPI code: CUUR0000SEAG01

ELI definition: All types and styles of wrist watches, pocket watches, and other types of watches meant to be worn on the body (i.e. ring watches) for men, women, and children. ELI excludes: Single purpose stopwatches which are not part of a standard watch.

Quality adjustment method: Imputation. The BLS estimates the price change between a discontinued watch and new watch via the price change of all other comparable watches in area.

New cars – CPI code: CUUR0000SS45011

ELI definition: All new automobiles, trucks and multi-purpose vehicles purchased for personal use. The vehicles are classified as either car or light truck segment. The light truck cluster includes pickup, vans, and sport utility vehicles. The body style term “crossover vehicle” is used in the industry to describe both cars and light trucks and to assist you with the appropriate cluster placement, please reference the SO 725 New Car and Truck List. ELI excludes: Optional extended warranties, titling, and registration; Used, commercial, “demonstrator”, and recreational vehicles.

Quality adjustment method: Production cost-based quality adjustment.

Table 1: Products by category

Hold-Up Industry	SEP-Reliant Industries	Non-SEP-Reliant Industries
Electricity, Urban Consumers	Telephone and facsimile Equipment merged with Telephone Hardware	Test equipment for electrical, radio, and communication circuits and motors
	Calculators, & Other Consumer Information Items	Watches
	Televisions	New Cars
	Other Video	Host Computers, Multi-users (Mainframes, UNIX, and PC Servers)
	Computers and Workstations (excluding portable)	Coin Operated Amusement Machines
	Audio Equipment	
	Photographic Equipment	
	Portable Computers, Laptops, PDAs, and Other Single User Computers	
	Video, audio, photographic, and information processing equipment and media (Figure 5 only)	

Note: For precise definitions and BLS or BEA Code see Appendix A.

Table 2: The effect of e-bay on the rate of price change in SEP industries

	(1) Price change	(2) Price change (detrended)	(3) Price change (detrended, Moore's law only)
Dummy SEP*Post 2006	0.012 (0.012)	0.012 (0.012)	0.013 (0.014)
SEP industry	-0.058*** (0.013)	0.0094 (0.013)	-0.053** (0.019)
Constant	-0.039 (0.021)	-0.035 (0.021)	0.050 (0.032)
Industry fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	201	201	169
R-squared	0.807	0.311	0.344

Note: The dependent variable is the quality adjusted change in the price of products in a particular industry and year. SEP industry is a dummy variable that equals one if the industry is a SEP-reliant industry, as defined in the text and listed in Table 1, and equals zero otherwise. Post 2006 is a dummy variable that equals one before 2007 and one from 2007 onward. Robust standard errors are reported in parentheses, and the designations, *, **, ***, indicate statistical significance at the ten, five, and one percent, respectively.

Figure 1
Quality-Adjusted Relative Prices of SEP-Intensive Consumer Products
Compared to Electricity Prices 1997-2013

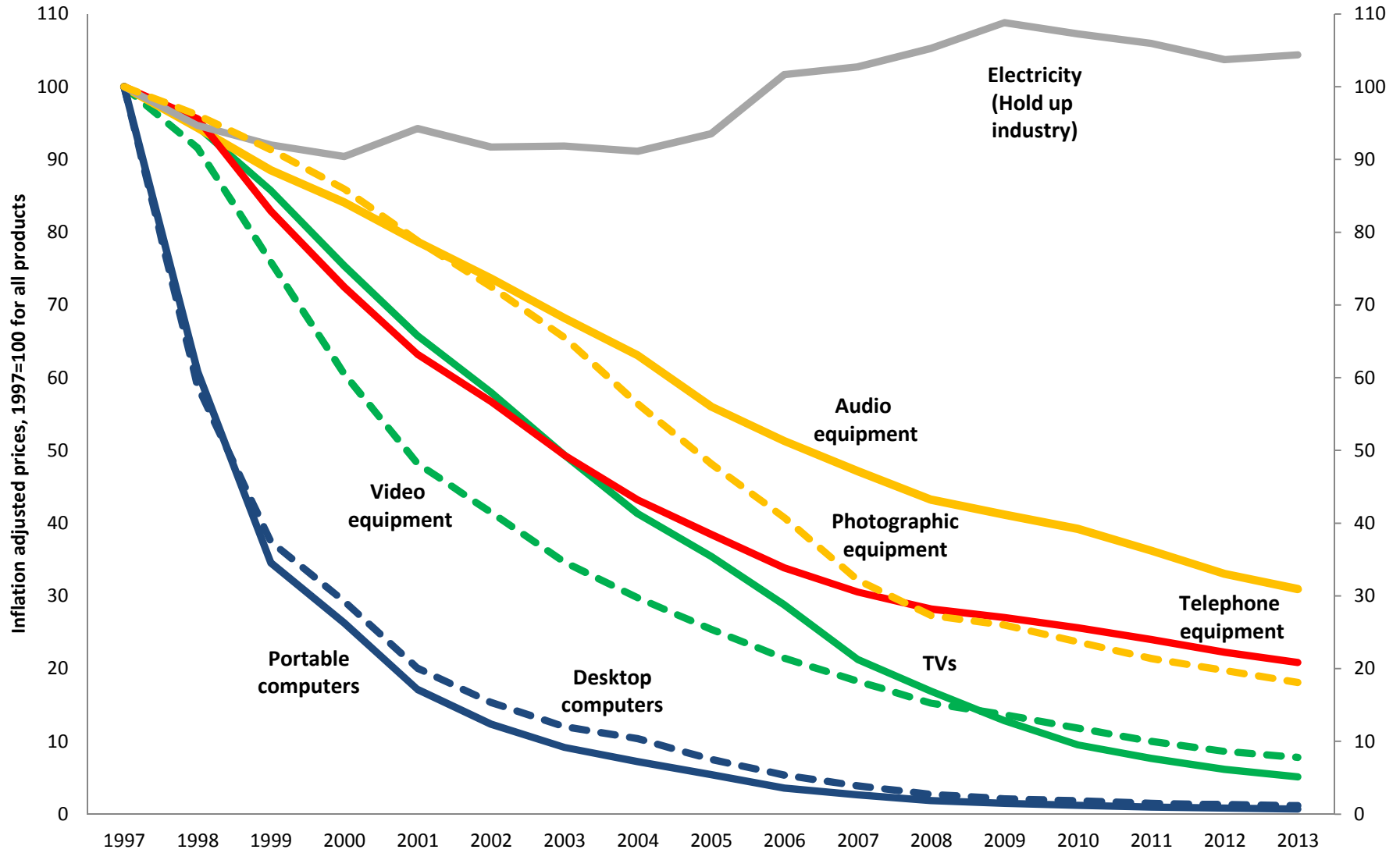


Figure 2
Quality-Adjusted Relative Prices of SEP-Intensive Products
Versus Automobiles , 1997-2013

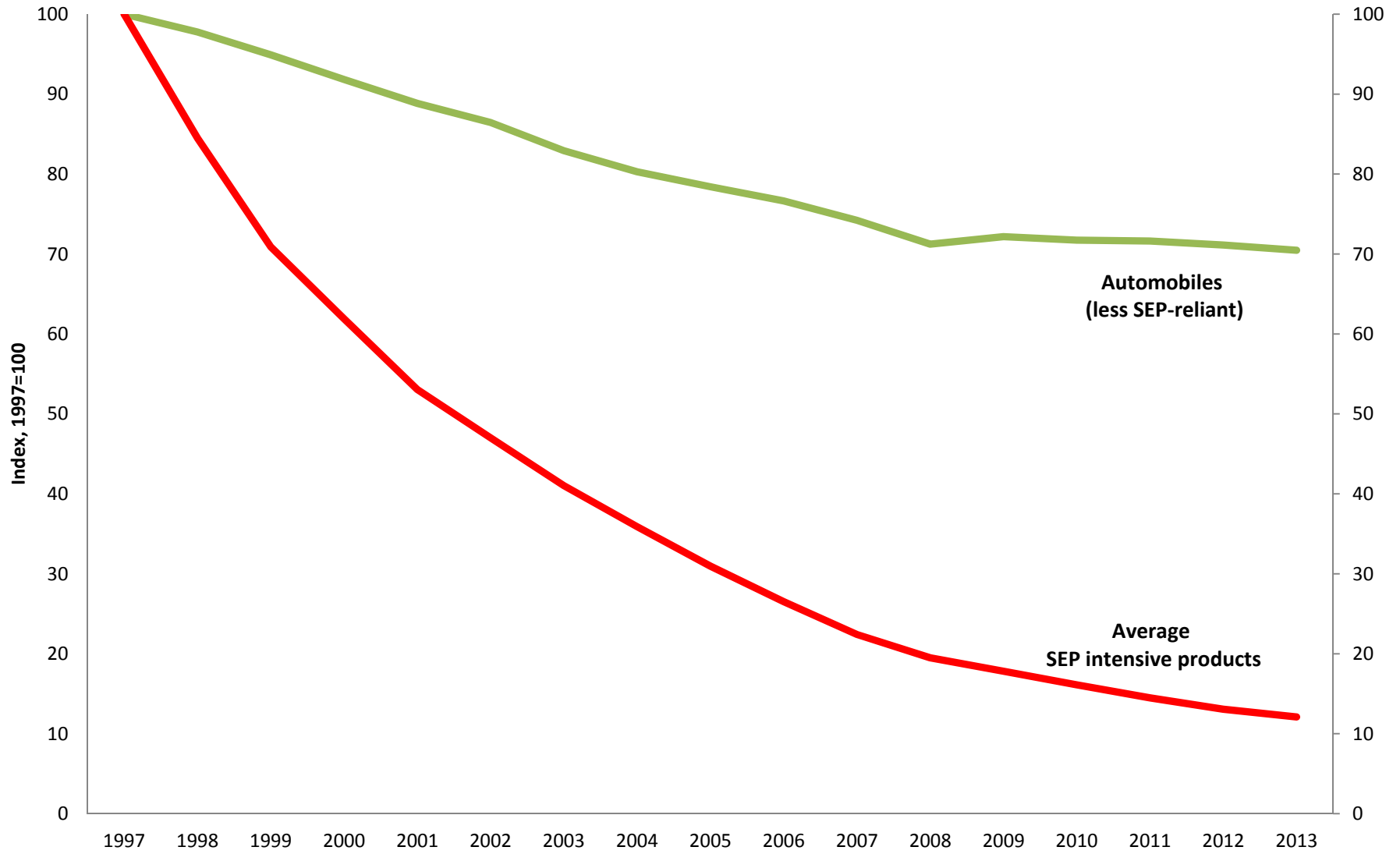


Figure 3
Quality-Adjusted Relative Prices of SEP-Intensive Products Compared
with other "Moore's Law" Products, 1997-2013

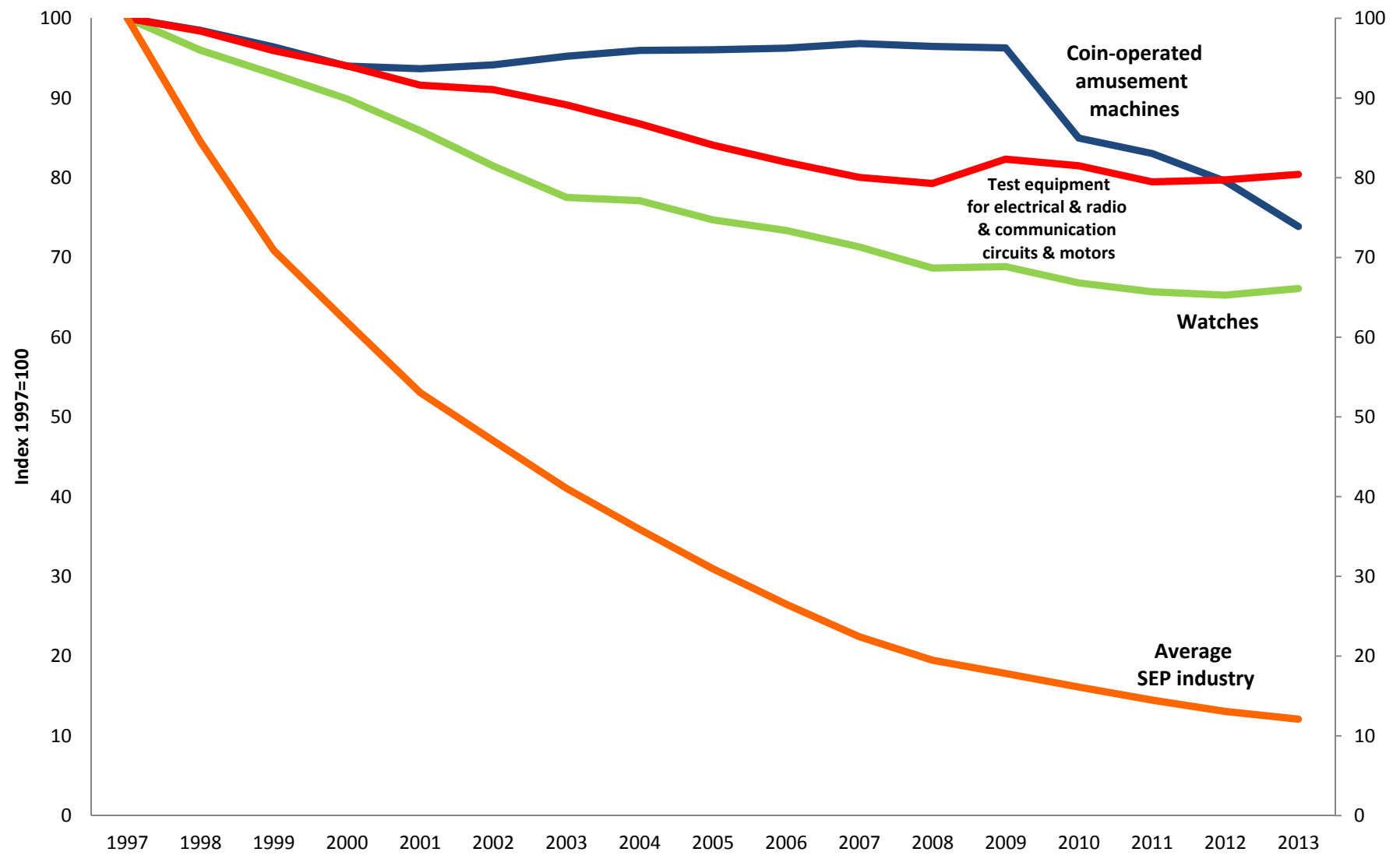


Figure 4
Quality Adjusted Relative Prices of Multi-User Mainframe Computers & Servers
Compared with SEP-Intensive Desktop and Portable Computers, 2004-2013

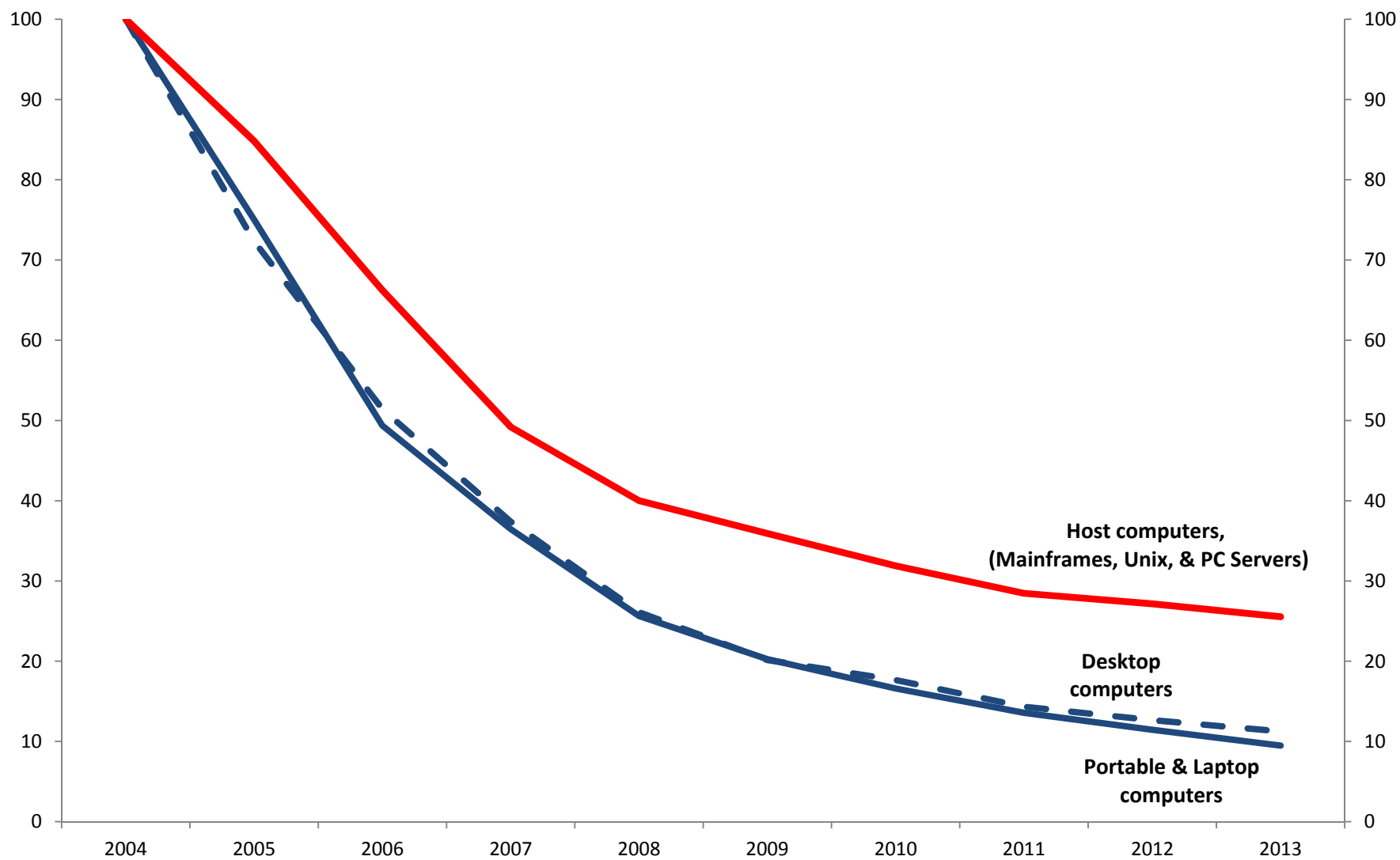


Figure 5
Quality-Adjusted Relative Prices of Electricity, Telephone Equipment ,
TVs and an Index of Video, Audio, Photographic and Information
Processing Equipment and Media, 1951-2013

