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AN EMPIRICAL EXAMINATION OF PATENT HOLDUP

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ABSTRACT

A large theoretical 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 holdup hypothesis: (1) SEP-reliant industries should experience more stagnant quality-adjusted prices than 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.

JEL: L1; O31; O38

I. INTRODUCTION

Economic theory offers conflicting perspectives on whether "patent holdup" is slowing American innovation. Based on seminal work by Oliver Williamson; Benjamin Klein, Robert Crawford, and Armen Alchian; Paul Joskow; and Sanford Grossman and Oliver Hart, the patent holdup hypothesis asserts that patent holders charge licensing royalties to manufacturing firms that exceed the true economic contribution of the patented technology, thereby discouraging

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innovation by manufacturers and hurting consumers.[1] Recent work, including by Carl Shapiro; Daniel Swanson and William Baumol; Joseph Farrell, John Hayes, Carl Shapiro, and Theresa Sullivan; Mark Lemley and Carl Shapiro; and Joseph Miller, emphasizes that the patent holdup problem is particularly acute for standard-essential patents (SEPs).[2] SEPs are patents on inventions that form the standards essential for the interoperability of connected systems, such as cell phones, personal computers, televisions, and audio-visual systems. It is theorized that holdup might be especially pronounced for SEPs because once manufacturing firms make large investments based on an accepted technological standard, SEP holders might be able to 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 holdup, 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.[3] In a similar vein, Richard Schmalensee, Gregory Sidak, and F. Scott Kieff and Anne Layne-Farrar 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

[1] *See* Oliver E. Williamson, *Hierarchical Control and Optimum Firm Size*, 75 J. POL. ECON. 123 (1967); Oliver E. Williamson, *Transaction-Cost Economies: The Governance of Contractual Relations*, 22 J.L. & ECON. 233 (1979); Benjamin Klein, Robert G. Crawford & Armen A. Alchian, *Vertical Integration, Appropriable Rents, and the Competitive Contracting Process*, 21 J.L. & ECON. 297 (1978); Paul L. Joskow, *Vertical Integration and Long-Term Contracts: The Case of Coal-Burning Electric Generating Plants*, 1 J.L. ECON. & ORG. 33 (1985); Paul L. Joskow, *Asset Specificity and the Structure of Vertical Relationships: Empirical Evidence*, 4 J.L. ECON. & ORG. 95 (1988); Sanford J. Grossman & Oliver D. Hart, *The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration*, 94 J. POL. ECON. 691 (1986).

[2] *See* Carl Shapiro, *Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard Setting*, *in* 1 INNOVATION POLICY AND THE ECONOMY 119 (Adam Jaffe, Josh Lerner & Scott Stern eds., MIT Press 2001); Daniel G. Swanson & William J. Baumol, *Reasonable and Nondiscriminatory (RAND) Royalties, Standards Selection, and Control of Market Power*, 73 ANTITRUST L.J. 1 (2005); Joseph Farrell, John Hayes, Carl Shapiro & Theresa Sullivan, *Standard Setting, Patents, and Hold-Up*, 74 ANTITRUST L.J. 603 (2007); Mark A. Lemley & Carl Shapiro, *Patent Holdup and Royalty Stacking*, 85 TEX. L. REV. 1991 (2007); Joseph S. Miller, *Standard Setting, Patents, and Access Lock-In: RAND Licensing and the Theory of the Firm*, 40 INDUS. L. REV. 351 (2007). For a comprehensive survey, see Edward J. Egan and David J. Teece, *Untangling the Patent Thicket Literature* (Univ. Cal. Berkeley Tusher Ctr. for Mgmt. Intellectual Capital, Working Paper No. 7, 2015).

[3] *See* Einer Elhauge, *Do Patent Holdup and Royalty Stacking Lead to Systematically Excessive Royalties*, 4 J. COMPETITION L. & ECON. 535 (2008); Bernhard Ganglmair, Luke M. Froeb & Gregory J. Werden, *Patent Hold-Up and Antitrust: How a Well-Intentioned Rule Could Retard Innovation*, 60 J. INDUS. ECON. 249 (2012); Richard A. Epstein, F. Scott Kieff & Daniel F. Spulber, *The FTC, IP, and SSOs: Government Hold-Up Replacing Private Coordination*, 8 J. COMPETITION L. & ECON. 1 (2012).

inventions and lowers investment in the costly, risky process of developing and patenting new technologies.[4]

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 and 2014. In 2015, the Congress is focused on two strikingly different bills—one that strengthens patent holder rights, and one that weakens those rights.

In this article, we contribute to these debates by providing empirical evidence on whether SEP holdup slows innovation. While an extensive theoretical literature examines the possibilities for SEP holdup, Damien Gerardin, Anne Layne-Farrar, and Jorge Padilla, and Jonathan Barnett note that there is very little empirical evidence that SEP holdup actually occurs, and that such evidence as exists is inconclusive.[5] Although policy analysts, lawyers, and practitioners provide anecdotes about SEP holdup, we are unaware of previous systematic evaluations of the core predictions emerging from theories based on principles of industrial organization (IO) of SEP holdup.

We assess one of the central empirical implications of the SEP holdup hypothesis: If SEPs are slowing the rate of innovation, then products that are highly reliant upon SEPs will experience slower rates of decrease in quality-adjusted prices (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 holdup 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 holdup. 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

[4] *See* Richard Schmalensee, *Standard-Setting, Innovation Specialists and Competition Policy*, 57 J. INDUS. ECON. 526 (2009); J. Gregory Sidak, *Patent Holdup and Oligopsonistic Collusion in Standard-Setting Organizations*, 5 J. COMPETITION L. & ECON. 123 (2009); F. Scott Kieff & Anne Layne-Farrar, *Incentive Effects from Different Approaches to Holdup Mitigation Surrounding Patent Remedies and Standard-Setting Organizations*, 9 J. COMPETITION L. & ECON. 1091 (2013).

[5] *See* Damien Geradin, Anne Layne-Farrar & Jorge A. Padilla, *Competing Away Market Power? An Economic Assessment of Ex Ante Auctions in Standard Setting*, 4 EUR. COMPETITION J. 443 (2008); Jonathan M. Barnett, *From Patent Thickets to Patent Networks: The Legal Infrastructure of the Digital Economy* (Stanford Univ. Hoover Inst., Working Paper No. 15001, 2014).

the prices paid by intermediate producers. However, when firms primarily purchase the product (for example, 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 Part VI.

To assess whether SEP holdup 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 holdup 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.[6] These are all industries that require interoperability and thus have formal organizations that meet regularly to agree on industry standards. Patents may read on technologies that are essential to the standard. Consequently, we categorize products as 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 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

[6] For example, Lemley and Shapiro 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." Lemley & Shapiro, *supra* note 2, at 1992. Their case studies focus on 3G cellular technologies, Wi-Fi 802.11 technologies, DVD media, the MP3 music format, and RFID chips. *Id.* at 2025–29. Farrell, Hayes, Shapiro, and Sullivan also call attention to the potential problem in IT industries. They motivate their article with seven cases: three of which are about computer technologies, two of which are about modems, and one of which is about cell phones. *See* Farrell, Hayes, Shapiro & Sullivan, *supra* note 2. Swanson and Baumol point to "computers, software, telecommunications, consumer electronics, and the Internet." *See* Swanson & Baumol, *supra* note 2, at 3. Miller argues that standard-setting organizations pervade the information and communication technology industries. *See* Miller, *supra* note 2.

Table 1. Products by category

Holdup industry	SEP-Reliant industries	Non-SEP-Reliant industries
Electricity, Urban Consumers	Telephone and facsimile equipment	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 Part VI.

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 holdup industry.

The second method for assessing whether SEP holdup 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 *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.[7] Critically for our analyses, proponents

[7] 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 "*eBay* Standard" for a permanent injunction. *See* Shyamkrishna Balganesh, *Demystifying the Right to Exclude: Of Property, Inviolability, and Automatic Injunctions*, 31 HARV. J.L. & PUB. POL'Y 593 (2008); Andrew Beckerman-Rodau, *The Aftermath of eBay v. MercExchange, 126 S. Ct. 1837*, 89 J. PAT. & TRADEMARK OFF. SOC'Y 631 (2007); Douglas Ellis, John Jarosz, Michael Chapman & L. Scott Oliver, *The Economic Implications (and Uncertainties) of Obtaining Permanent Injunctive Relief After* eBay v. MercExchange, 17 FED. CIR. B.J. (2007); Benjamin H. Diessel, *Trolling for Trolls: The Pitfalls of the Emerging Market Competition Requirement for Permanent Injunctions in Patent Cases Post-eBay*, 106 MICH. L. REV. 305 (2007); Rebecca A. Hand, eBay v. MercExchange*: Looking at the Cause and Effect of a Shift in the Standard for Issuing Patent Injunctions*, 25 CARDOZO ARTS & ENT. L.J. 461 (2007); John M. Golden, *"Patent Trolls" and Patent Remedies*, 85 TEX. L. REV. 2111 (2007), Leslie T. Grab, *Equitable Concerns of* eBay v. Mercexchange*: Did the Supreme Court Successfully Balance Patent Protection Against Patent Trolls?*, 8 N.C. J. L. & TECH. 81 (2006); Miranda Jones, *Permanent Injunction, A Remedy by Any*

of the SEP holdup hypothesis advocate for limiting injunctions by SEP holders.[8] They argue that such limits would spur innovation by reducing the excessive power of SEP holders.[9] 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 *eBay*, 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 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 holdup hypothesis. On the contrary, we find that products that are SEP-reliant have experienced faster price declines than any other good in the Consumer Price Index (CPI) 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 relative prices of electricity 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 holdup industry, they are fast relative to other patent-intensive products that benefit from Moore's Law but 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

Other Name Is Patently Not the Same: How eBay v. MercExchange *Affects the Patent Right of Non-Practicing Entities*, 14 GEO. MASON L. REV. 1035 (2007); Richard B. Klar, *Ebay Inc. V. Mercexchange, L.L.C.: The Right to Exclude Under U.S. Patent Law and the Public Interest*, 88 J. PAT. & TRADEMARK OFF. SOC'Y 852 (2006); Richard B. Klar, *The United States Supreme Court's Decision in* eBay v. MercExchange*: How Irreparable the Injury to Patent Injunctions?*, 14 WIDENER L. REV. 239 (2008); Paul M. Mersino, *Patents, Trolls, and Personal Property: Will eBay Auction Away a Patent Holder's Right to Exclude?*, 6 AVE MARIA L. REV. 307 (2007); Jeremy Mulder, *The Aftermath of* eBay*: Predicting When District Courts Will Grant Permanent Injunctions in Patent Cases*, 22 BERKELEY TECH. L.J. 67 (2007); George M. Newcombe, Jeffrey E. Ostro, Patrick E. King & Gabriel N. Rubin, *Prospective Relief for Patent Infringement in a Post-*eBay *World*, 4 N.Y.U. J.L. & BUS. 549 (2008); Robert I. Reis, *Rights and Remedies Post eBay v. MercExchange—Deep Waters Stirred*, 2 AKRON INTELL. PROP. J. 133 (2008); Doug Rendleman, *The Trial Judge's Equitable Discretion Following eBay v. MercExchange*, 27 REV. LITIG. 63 (2008); Neal Solomon, Analysis of the "Four-Factor Test" in Patent Cases Post-*eBay* (June 11, 2010) (unpublished manuscript), http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1623978; Mitchell G. Stockwell, *Implementing* eBay*: New Problems in Guiding Judicial Discretion and Enforcing Patent Rights*, 88 J. PAT. & TRADEMARK OFF. SOC'Y 747 (2006); Yixin H. Tang, *The Future of Patent Enforcement After* eBay v. MercExchange, 20 HARV. J.L. & TECH. 235 (2006).

[8] Lemley & Shapiro, *supra* note 2.

[9] Sidak, however, challenges the plausibility of the Lemley-Shapiro holdup conjecture with respect to the decision in *eBay. See* J. Gregory Sidak, *Holdup, Royalty Stacking, and the Presumption of Injunctive Relief for Patent Infringement: A Reply to Lemley and Shapiro*, 92 MINN. L. REV. 714 (2008); J. Gregory Sidak, *The Meaning of FRAND, Part II: Injunctions*, 11 J. COMPETITION L. & ECON. 201 (2015).

of innovation of SEP-reliant products would have been still faster if SEP holdup were not slowing innovation. We address these concerns formally when we conduct the quasi-natural experiment based on *eBay*. We can address these concerns informally be examining only digital technologies that follow Moore's Law.[10] If the SEP holdup hypothesis holds, we would find that the quality-adjusted prices of Moore's Law products that are non-SEP-reliant will 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. This finding, however, does not fully address the concern that 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 *eBay* on SEP-reliant and non-SEP-reliant industries.

In examining the quasi-natural experiment involving *eBay*, we also cannot reject the null hypothesis of no SEP holdup. The difference-in-differences results do not indicate that quality-adjusted prices fall faster in SEP-reliant industries after *eBay*. 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 holdup view, we cannot reject the null hypothesis that *eBay* 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 holdup 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 (*eBay*) 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.

It is also important to emphasize that we are not claiming that individual firms never attempt to engage in behavior that can be characterized as holdup. Rather, we do not find evidence consistent with the hypothesis that SEP holdup is a systemic problem.

The remainder of the article is organized as follows. Part II describes patent holdup and uses a simple theoretical model to frame its empirical implications. Part III evaluates the testable implications by simply graphing the evolution of quality-adjusted prices of the products in different industries. Part IV 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. Part V concludes.

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

II. HOLDUP AND ITS TESTABLE IMPLICATIONS

A. Patent Holdup

The term "holdup" describes the following theoretical 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 Firm A cannot anticipate every future action taken by Firm B. 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 famously described this situation as "self-interest seeking with guile."[11] According to the theory, 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.

One quintessential example of holdup 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. She opportunistically changes the terms of the contract, pointing to "excuses" such as differences in the size or weight of the trucks being used, changes in the constructions costs for necessary improvements to the roadway, or any number of similar "problems" that the mine owner could not have foreseen at the time the contract was signed, but which the owner of the pass had been planning to exploit ex post. 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.[12]

[11] OLIVER E. WILLIAMSON, THE ECONOMIC INSTITUTIONS OF CAPITALISM: FIRMS, MARKETS, RELATIONAL CONTRACTING 47 (Free Press 1985).

[12] 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

Holdup is not, therefore, a marginal effect. On the contrary, the theory implies that holdup is a protracted force that can be a crucial determinant of the performance of an entire industry. Any attempt by the victims of holdup to increase efficiency in order to restore their profitability will result in a successive round of opportunistic ex post appropriation of their quasi-rents.

SEP holdup is a variety of this general holdup problem. Instead of a land owner levying an excessive toll for a right of way, SEP holdup 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. Since complex products involve hundreds, if not thousands, of SEPs, and because SEP holders do not know the royalties charged by other SEP holders, the SEP holdup hypothesis implies that uncoordinated SEP holders may extract most, if not all, of the quasi-rents of the manufacturing company via multiple "toll booths"—a theoretical construct known as "royalty stacking."

B. Implications of Patent Holdup

The extraction of the manufacturing firm's quasi-rents by the SEP holder (or holders) has at least three 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. 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 research and development (R&D) spending for future rounds of innovation, or pass these additional costs on to consumers. 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 holdup hypothesis is that consumers either face higher prices or lower quality products than they would if

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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 STEPHEN H. HABER, ARMANDO RAZO & NOEL MAURER, THE POLITICS OF PROPERTY RIGHTS: POLITICAL INSTABILITY, CREDIBLE COMMITMENTS, AND ECONOMIC GROWTH IN MEXICO, 1876–1929 at 236–84 (Cambridge Univ. Press 2003).

holdup were not taking place. This yields the core testable hypotheses discussed in Part I:

(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.

C. SEP Holdup and Quality-Adjusted Prices: A Model

In this Part, we use a simple model to illustrate the impact of SEP holdup 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, X and Y, and suppose that productivity and quality in X grow one percentage point faster than in Y. Then, X's quality-adjusted relative price falls one percentage point faster than Y's.

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 total factor productivity and φ measures quality.

Goods markets. The nominal demand for good i is $Y_i(p_i)$ and

$$\eta_i = \frac{p_i Y_i'}{Y_i}$$

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

$$\frac{p_i - c_i}{p_i} = \frac{\theta_i}{\eta_i}, \tag{1}$$

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.[13]

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. w Let be the nominal wage and r the nominal rental price of capital. Then profit maximization implies that K_i and L_i solve

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

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—that is,

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

and

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

2. *Some Results*

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

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

13 We follow David Genesove and Wallace Mullin's variation on Timothy Bresnahan's work. *See* David Genesove & Wallace P. Mullin, *Testing Static Oligopoly Models: Conduct and Cost in the Sugar Industry, 1890–1914*, 29 RAND J. ECON. 355 (1998); Timothy F. Bresnahan, *Empirical Studies in Industries with Market Power*, *in* 2 HANDBOOK OF INDUSTRIAL ORGANIZATION (Richard Schmalensee & Robert D. Willig eds., North-Holland 1989).

and

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

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 $(\hat{A}_i + \hat{\varphi}_i)$, the sum of total factor productivity increases and quality improvements. That is, innovation directly influences prices.

Now it is easy to show that

$$\hat{y}_{L_i} - \hat{y}_{K_i} = \hat{K}_i - \hat{L}_i = \hat{w} - \hat{r}. \tag{6}$$

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

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

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.

3. *The Differential Rate of Innovation and the Rate of Change of Relative Prices*

Let p be a price index such that

$$p \equiv \Pi_i(p_i)^{\lambda_i}, \tag{8}$$

where λ_i is the share of industry *i* in the index, and $\Sigma_i\lambda_i = 1$. 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

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

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 of *i* is thus

$$\hat{p}_i - \hat{p} = -[(\hat{A}_i + \hat{\varphi}_i) - (\hat{A} + \hat{\varphi})] + (\alpha_i - \bar{\alpha})\hat{w} + (1 - \alpha_i - \overline{1-\alpha})\hat{r} + (\hat{m}_i - \hat{m})$$
$$\equiv -[(\hat{A}_i + \hat{\varphi}_i) - (\hat{A} + \hat{\varphi})] + \varepsilon_i \qquad (9)$$

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

Expression (9) says that in equilibrium, the rate of change of industry *i*'s relative price equals the inverse of industry *i*'s differential rate of productivity and quality growth, $(\hat{A}_i + \hat{\varphi}_i) - (\hat{A} + \hat{\varphi})$, 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 difference between the growth rate of two nominal prices,

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

reflects the differential rate of productivity and quality growth up to a mean-zero error term. 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. W.E.G. Salter 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.[14] Nicholas Oulton and Mary O'Mahony replicated this result by studying 136 manufacturing industries in Britain between 1953 and 1986.[15] John Kendrick and Elliot Grossman 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's work.[16] William Nordhaus extended Kendrick and Grossman's data to 2001 with similar results.[17]

4. *Relative Price Change and the Holdup Hypothesis: Observable Implications*

The holdup hypothesis argues that holdup will slow innovation. It follows that it should lead to a slower rate of decline $-[(\hat{A}_i - \hat{\varphi}_i) - (\hat{A} - \hat{\varphi})]$ of the

[14] *See* W. E. G. SALTER, PRODUCTIVITY AND TECHNICAL CHANGE (Cambridge Univ. Press 1960).

[15] *See* NICHOLAS OULTON & MARY O'MAHONY, PRODUCTIVITY AND GROWTH: A STUDY OF BRITISH INDUSTRY, 1954–1986 (Cambridge Univ. Press 1994).

[16] *See* JOHN W. KENDRICK & ELLIOT S. GROSSMAN, PRODUCTIVITY IN THE UNITED STATES: TRENDS AND CYCLES (Johns Hopkins Univ. Press 1980).

[17] *See* William D. Nordhaus, *Baumol's Disease: A Macroeconomic Perspective*, 8 B. E. J. MACROECONOMICS 1 (2008).

quality-adjusted relative price. Hence, if holdup 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 (for example, 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 (*eBay*) that reduce the power of SEP holders should accelerate reductions in quality-adjusted prices.

III. EMPIRICAL ANALYSES: THE EVOLUTION OF QUALITY-ADJUSTED PRICES

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

A. Categorizing Industries

SEPs have become particularly common over the past two decades in the production and operation of digital electronic products—for example, personal computers, phones, televisions, and audio systems. The reason is that these products must be interoperable 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 (SSOs), which include upstream component manufacturers and downstream device manufacturers, as well as firms that operate the networks that link devices together. Patents that read on the technical standards established by the SSO can then be declared 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 holdup literature, by categorizing as SEP-reliant those products whose core functions require interoperability 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. Table 1 summarizes the information about the products in both categories.[18]

[18] 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 article.

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 interoperability and compatibility, such as watches, coin operated gaming machines, electrical test equipment, and multi-user (for example, mainframe) computers. Quality-adjusted price data on these products therefore provide us with a second source of analytic leverage. When we turn to the difference-in-differences estimation in Part 4, we further control for inherent differences in rates of innovation across industries by detrending 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 holdup, 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 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.[19] 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

[19] *See* International Comparisons of Electricity Regulation (Richard J. Gilbert & Edward P. Khan eds., Cambridge Univ. Press 1996).

and that is characterized by scale economies remains, however. Thus, the electricity industry is still characterized by holdup 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 only begun to reach energy management and use within homes, businesses, and public buildings within the past few years.[20]

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 Part VI. The data show that the price of electricity has barely moved over those 16 years, which is exactly what one would expect of a holdup industry characterized by slow rates of innovation.

B. 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,

[20] Our point is not that innovation by electric utilities is zero or even that the comparative rate of innovation in electricity will remain slow. Since 2008, for example, some utilities have been moving toward "smart grid" technologies that will enable real-time load management. This new technology requires a new meter that replaces the century-old electromechanical meter with a solid-state digital meter that communicates vital information back to the utility. The point is simply that for much of the period under investigation, the rate of innovation has been relatively slow.

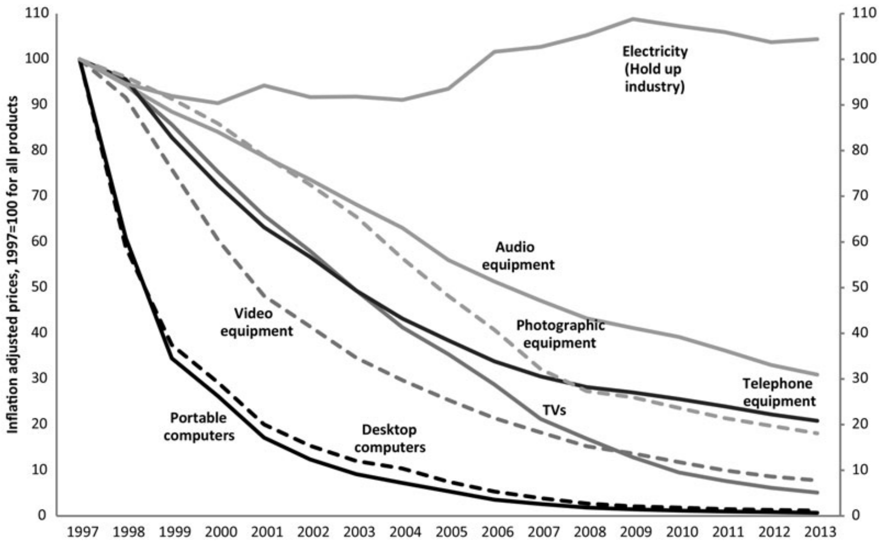

Figure 1. Quality-adjusted relative prices of SEP-intensive consumer products compared with electricity prices, 1997–2013.

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 neither interoperable nor 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 holdup—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 have not stagnated relative to a classic holdup industry or a benchmark, patent-intensive, non-SEP-reliant industry. These figures do not, however, address the possibility that patent-intensive SEP-reliant industries were—for technological reasons—more technology-dynamic than these 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 holdup 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

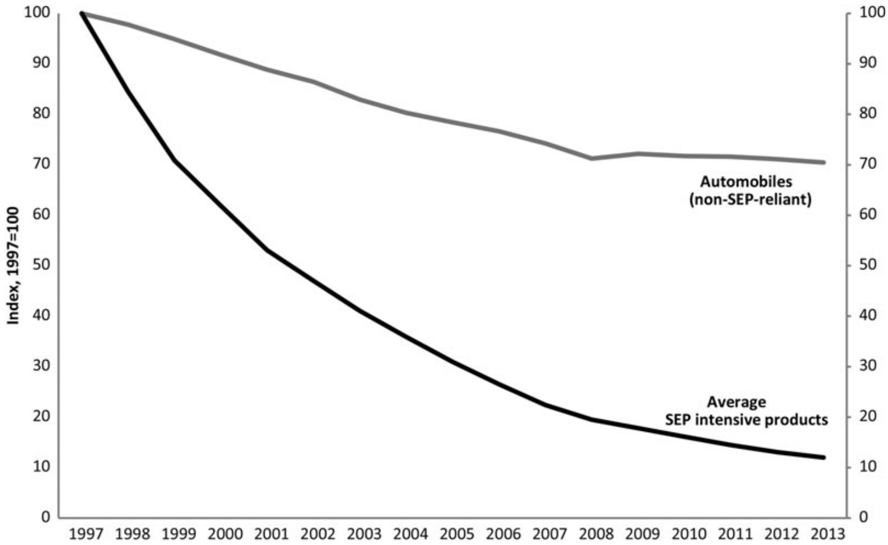

Figure 2. Quality-adjusted relative prices of SEP-intensive products versus automobiles, 1997–2013.

Moore's Law and hence restrict our analysis to digital products that differ in their reliance on SEPs. Second, we address this more formally by conducting a quasi-natural experiment based on *eBay*.

C. 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 holdup 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. A 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,

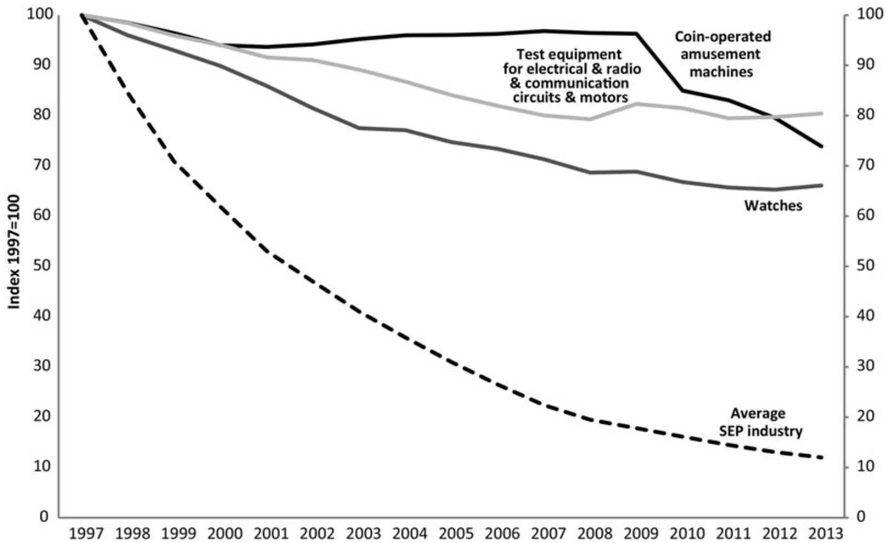

Figure 3. Quality-adjusted relative prices of SEP-intensive products compared with other Moore's Law products, 1997–2013.

slow-clock-speed PCs. The implication is that the empirical regularity called Moore's Law is observed in the United States because of its institutions, which include the specification of intellectual property rights.

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 interoperability 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 interoperability 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 a set of benchmark 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

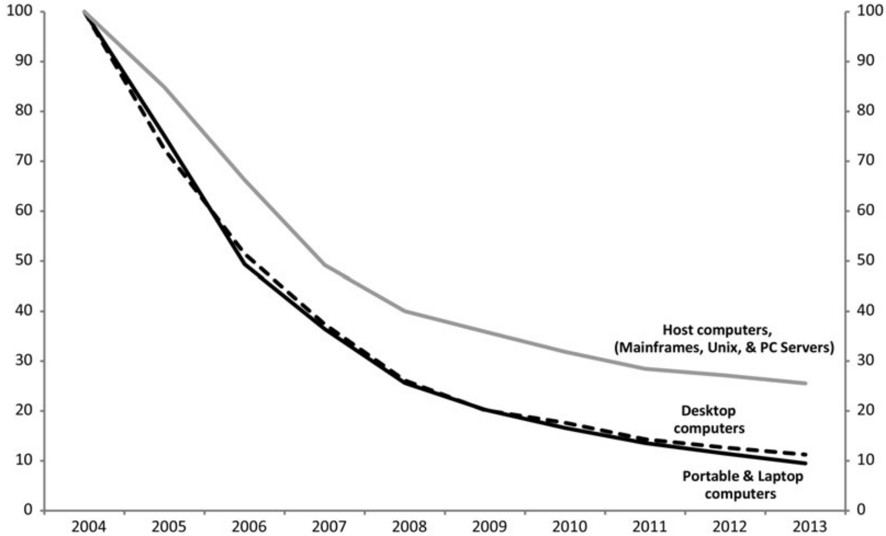

Figure 4. Quality-adjusted relative prices of multi-user mainframe computers and servers compared with SEP-intensive desktop and portable computers, 2004–2013.

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 because they do not have to be designed to be interoperable and compatible. Indeed, mainframes are often used for specific tasks, with proprietary architectures and software. If the SEP holdup 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.

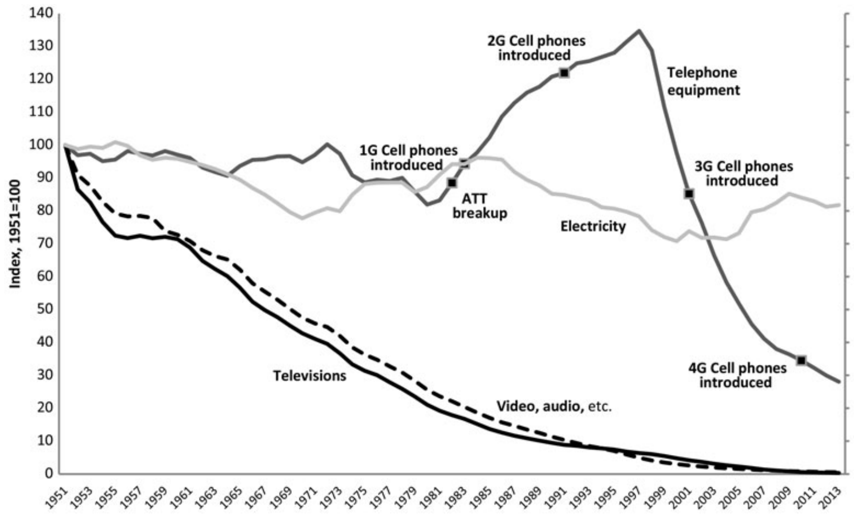

Figure 5. Quality-adjusted relative prices of telephone equipment, TVs and an index of video, audio, photographic, and information-processing equipment and media, 1951–2013.

D. 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).[21] 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 holdup.[22] 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

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

[22] A skeptic perhaps could argue that electricity prices have been loaded with environmental costs that were (inefficiently) ignored in earlier years. She might also argue that electricity prices might reflect rising costs of fossil fuels, masking innovation. As an empirical matter, roughly one half of the retail price of electricity is associated with generation costs, and of that only one half is associated with the cost of fossil fuels. Generating companies do have to install filters to abate emissions, but that cost is a small fraction of the cost of producing electricity. All in all, changes in fossil fuel prices are probably behind the observed fluctuations in electricity prices, which followed the increase in coal and gas prices in the 1970s and their fall in the 1980s and 1990s. But the fact that the relative price of retail electricity follows fuel price fluctuations confirms that productivity growth in distribution has been stagnant.

been in 1951. The same is true for the index of video, audio, photographic, and information processing equipment.

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 $9,400 in 2015 dollars), weighed more than a kilo, and had a battery life of a half 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 10 percent per year.

Note that the trajectory of the relative price of telephone equipment is the opposite of what the patent holdup hypothesis would predict. As long as telephone equipment was produced by a subsidiary of AT&T, and thus by definition could not have been subject to holdup, 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 holdup 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 *eBay* on SEP-reliant and non-SEP-reliant industries.

IV. EMPIRICAL ANALYSES: *EBAY* AS A QUASI-NATURAL EXPERIMENT

One argument made in the SEP holdup 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.[23] The *eBay* decision

[23] 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

therefore allows us to leverage variance across time as well as variance across products. If holdup were 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 that are non-SEP-reliant. If we fail to detect that more rapid decrease, it implies that holdup 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:

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

where $P_{i,t}$ is the change in 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; $\mathrm{Post2006}_t$ 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 *eBay* spurred the comparative rate of innovation in SEP-reliant industries. If the regression analyses do not reject the hypothesis that $\beta = 0$, then the data would not reject the null hypothesis that *eBay* 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 *eBay* did not accelerate the relative rate of innovation in SEP-reliant industries. The *eBay* decision coefficient on price change $\mathrm{SEP}_i \times \mathrm{Post2006}_i$ is positive and insignificant in column [1]. In searching to find a specification that is consistent with the SEP holdup hypothesis, we extend the analyses in two ways. One might think that different products have inherently different potential rates of innovation (that is, that automobiles cannot be improved as quickly as smartphones). That is, SEP-reliant and non-SEP-reliant industries might display different trends before treatment. In column [2], we therefore detrend 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

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Court's "*eBay* Standard" for a permanent injunction. *See* Balganesh, *supra* note 7; Beckerman Rodau, *supra* note 7; Ellis, Jarosz, Chapman & Oliver, *supra* note 7; Diessel, *supra* note 7; Hand, *supra* note 7; Golden, *supra* note 7, Grab, *supra* note 7; Jones, *supra* note 7; Klar, *Ebay Inc. V. Mercexchange, L.L.C.*, *supra* note 7; Klar, *The United States Supreme Court's Decision in* eBay v. MercExchange, *supra* note 7; Mersino, *supra* note 7; Mulder, *supra* note 7; Newcombe, Ostro, King & Rubin, *supra* note 7; Reis, *supra* note 7; Rendleman, *supra* note 7; Solomon, *supra* note 7; Stockwell, *supra* note 7; Tang, *supra* note 7.

Table 2. The effect of *eBay* on the rate of price change in SEP industries

	Price change [1]	**Price change (detrended) [2]**	**Price change (detrended, Moore's Law only) [3]**
Dummy SEP*Post 2006	0.012	0.012	0.013
	(0.012)	(0.012)	(0.014)
SEP industry	–0.058***	0.0094	–0.053**
	(0.013)	(0.013)	(0.019)
Constant	–0.039	–0.035	0.050
	(0.021)	(0.021)	(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

Notes: 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.

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 includes only digital electronic products. Once again, we get a coefficient with the "wrong" sign that is not statistically significant. Finally, employing a jackknife approach—serially dropping products from the regression—we 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.

V. CONCLUSIONS

In this article, 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 holdup. We find that prices of SEP-reliant products have fallen at rates that are fast not only when compared with a classic holdup industry, but that are fast even compared with 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 holdup.

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. As any number of scholars have noted, major innovations do not occur because of a patent, but because someone has figured out how to turn a patented technology into a viable business model. We speculate that creating and sustaining a viable business model in a complex, interoperable product whose underlying technology is characterized by rapid change requires that multiple firms cooperate continuously over long periods of time. As described by Gregory Sidak and Edward Egan and David Teece, standard-setting organizations can provide exactly this kind of forum for firms that invent and firms that implement to cooperate over the long run.[24] 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.

APPENDIX

In this appendix we describe each price series that we use and mention the method used to adjust for quality.

Our default source is the BLS's Consumer Price Series. We prefer these data because they reflect 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 are 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's 2014 National Income and Product Accounts Handbook.[25]

Electricity; CPI code: CUUR0000SEHF01

ELI[26] 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.

[24] *See* J. Gregory Sidak, *The Meaning of FRAND, Part I: Royalties*, 11 J. COMPETITION L. & ECON. 201 (2013); Egan & Teece, *supra* note 2.

[25] DEPARTMENT OF COMMERCE, BUREAU OF ECONOMIC ANALYSIS, NATIONAL INCOME AND PRODUCT ACCOUNTS HANDBOOK tbl.2.4.4 (Bureau Econ. Analysis 2014).

[26] "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, HANDBOOK OF METHODS ch. 17, at 13 (Bureau Labor Statistics 2013).

Quality adjustment method: Electricity is not quality-adjusted.

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).[27] This series 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 subcomponent is the BEA series DCTERG3.

This price series is divided into three 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 two 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. This subcomponent is not included in the BEA series DCTERG3.
Quality adjustment method: The BEA does not perform an independent quality adjustment. However, the BLS does a hedonic quality adjustment to build the CPI series.

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).

[27] For the source data of table 2.4.4 for the price indices for personal consumption expenditures, see Department of Commerce, Bureau of Economic Analysis, Price Indexes for PCE: Source Data (Bureau Econ. Analysis 2014), https://www.bea.gov/national/xls/pce_deflators_faq_new_stub.xls.

Quality adjustment method: Quality is adjusted with the hedonic price method since 1999.[28]

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-inch, 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 inches 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.[29]

[28] Mary Kokoski, Keith Waehrer & Patricia Rozaklis, Using Hedonic Methods for Quality Adjustment in the CPI: The Consumer Audio Products Component (1999) (unpublished manuscript), http://www.bls.gov/cpi/cpiaudio.htm.

[29] *Id.*

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 inches 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.[30]

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.

[30] *Id.*

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.[31]

Quality adjustment method: Hedonic price method.[32]

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.

Data is missing for 2003 to 2007. We estimate observations for those years by linear interpolation.

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 (that is, 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

31 *See* INTERNATIONAL MONETARY FUND, PRODUCER PRICE INDEX MANUAL: THEORY AND PRACTICE 261–63 (Int'l Monetary Fund 2004).

32 *See* DEPARTMENT OF COMMERCE, BUREAU OF LABOR STATISTICS, HOW BLS MEASURES PRICE CHANGE FOR PERSONAL COMPUTERS AND PERIPHERAL EQUIPMENT IN THE CONSUMER PRICE INDEX (June 26, 2008); Dave Wasshausen & Brent R. Moulton, The Role of Hedonic Methods in Measuring Real GDP in the United States (2007) (unpublished manuscript), http://www.bea.gov/papers/pdf/hedonicGDP.pdf.

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.