THE FABLE OF THE KEYS

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This is a very lightly edited version of our paper that appeared in the October 1990 issue of the Journal of Law and Economics.

A. Introduction

The term 'standard' can refer to any social convention (standard of conduct, legal standards), but it most often refers to conventions that require exact uniformity (standards of measurement, computer operating systems). Current efforts to control the development of high-resolution television, multitasking computer-operating systems, and videotaping formats have heightened interest in standards.

The economics literature on standards has focused recently on the possibility of market failure with respect to the choice of a standard. In its strongest form, the argument is essentially this: an established standard can persist over a challenger, even where all users prefer a world dominated by the challenger, if users are unable to coordinate their choices. For example, each of us might prefer to have Beta-format videocassette recorders as long as prerecorded Beta tapes continue to be produced, but individually we do not buy Beta machines because we don't think enough others will buy Beta machines to sustain the prerecorded tape supply. I don't buy a Beta format machine because I think that you won't; you don't buy one because you think that I won't. In the end, we both turn out to be correct, but we are both worse off than we might have been. This, of course, is a catch-22 that we might suppose to be common in the economy. There will be no cars until there are gas stations there will be no gas stations until there are cars. Without some way out of this conundrum, joyriding can never become a favorite activity of teenagers.[1]

The logic of these economic traps and conundrums is impeccable as far as it goes, but we would do well to consider that these traps are often escaped in the market. Obviously, gas stations and automobiles do exist, so participants in the market must use some technique to

unravel such conundrums. If this catch-22 is to warrant our attention as an empirical issue, at a minimum we would hope to see at least one real-world example of it. In the economics literature on standards,[2] the popular real-world example of this market failure is the standard QWERTY typewriter keyboard[3] and its competition with the rival Dvorak keyboard.[4] This example is noted frequently in newspaper and magazine reports, seems to be generally accepted as true, and was brought to economists' attention by the papers of Paul David.[5] According to the popular story, the keyboard invented by August Dvorak, a professor of education at the University of Washington, is vastly superior to the QWERTY keyboard developed by Christopher Sholes that is now in common use. We are to believe that, although the Dvorak keyboard is vastly superior to QWERTY, virtually no one trains on Dvorak because there are too few Dvorak machines, and there are virtually no Dvorak machines because there are too few Dvorak typists.

This article examines the history, economics, and ergonomics of the typewriter keyboard. We show that David's version of the history of the market's rejection of Dvorak does not report the true history, and we present evidence that the continued use of QWERTY is efficient given the current understanding of keyboard design. We conclude that the example of the Dvorak keyboard is what beehives and lighthouses were for earlier market-failure fables. It is an example of market failure that will not withstand rigorous examination of the historical record.[6]

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1 This trap is treated more seriously in the literature on standards than in other economics literature. This reflects a supposition that foresight, integration, or appropriation are more difficult in the case of standards.

[2] See, for example, Farrell and Saloner (1985), Katz and Shapiro (1985), or Tirole (1988).

[3] QWERTY stands for the arrangement of letters in the upper left-hand portion of the keyboard below the numbers. This keyboard is also known as the Sholes, and Universal.

4 This is also sometimes known as the DSK keyboard for Dvorak Simplified Keyboard or the simplified keyboard). As explained below, the keys are arranged in a different order.

5 Paul David (1985) and (1986).

[6] See Ronald Coase (1974) and Steven N. Cheung (1973). These two papers examined how the market provided the services of lighthouses and beehives respectively. These examinations were important since these two examples had been put forward as instances where markets could not work, as the QWERTY example has been put forward. Our debt is obvious.

B. Some Economics Of Standards

Some standards change over time without being impaired as social conventions. Languages for example, evolve over time, adding words and practices that are useful and winnowing features that have lost their purpose. Other standards are inherently inflexible. Given current technologies, it won't do, for example, for broadcast frequencies to drift in the way that orchestral tuning has. A taste for a slightly larger centimeter really can't be accommodated by a sequence of independent decisions the way that increased use of contractions in academic writing can. Obviously, if standards can evolve at low cost, they would be expected to evolve into the forms that are most efficient (in the eyes of those adopting the standards). Conversely, an inappropriate standard is most likely to have some permanence where evolution is costly.

In their influential article on standards, Joseph Farrell and Garth Saloner presented a formal exploration of the difficulties associated with changing from one standard to another.[7] They constructed hypothetical circumstances that might lead to market failure with respect to standards. To refer to the condition in which a superior standard is not adopted, they coined the phrase "excess inertia". Excess inertia is a type of externality: each nonadopter of the new standard imposes costs on every other potential user of the new standard and there is no third party (entrepreneur) in the model who can rearrange incentives to achieve efficient adoption. In the case of excess inertia, the new standard can be clearly superior to the old standard, and the sum of the private costs of switching to the new standard can be less than the sum of the private benefits, and yet the switch does not occur. This is to be distinguished from the far more common case where a new standard is invented that is superior to the old, but for which the costs of switching are too high to make the switch practicable. Users of the old standard may regret

[7] Farrell and Saloner (1985).

their choice of that standard, but their continued use of the old standard is not inefficient if the costs of switching are greater than the benefits.

Farrell and Saloner's construct is useful because it shows the theoretical possibility of a market failure and also demonstrates the role of information. There is no possibility of excess inertia in their model if all participants can communicate perfectly.[8] In this regard, standards are not unlike other externalities in that costs of transacting are essential. Thus, standards can be understood within the framework that Ronald Coase offered decades ago in his paper on externalities.[9]

By their nature, this model and others like it must ignore many factors in the markets they explore. Adherence to an inferior standard in the presence of a superior one represents a loss of some sort: such a loss implies a profit opportunity for someone who can figure out a means of appropriating some of the value made available from changing to the superior standard. Furthermore, institutional factors such as head starts from being first on the market, patent and copyright law, brand names, tie-in sales, discounts, and so on, can also lead to appropriation possibilities (read "profit opportunities") for entrepreneurs, and with these opportunities we expect to see activity set in motion to internalize the externalities. The greater the gap in performance between two standards, the greater are these profit opportunities, and the more likely that a move to the efficient standard will take place. As a result, a clear example of excess

[8] Inertia is not necessarily inefficient. Some delay in settling on a standard will mean that relatively more is known about the associated technology and the standards themselves by the time most users commit to a technology. See the well-known discussion of Harold Demsetz (1969) on the nature of efficiency. If God can costlessly cause the adoption of the correct standard, any inertia is excessive (inefficient) in comparison. But it seems ill advised to hold this up as a serious benchmark Excessive inertia should be defined relative to some achievable result. Further, some reservation in committing to standards will allow their creators to optimize standards rather than rushing them to the market to be first. If the first available standard were always adopted, then standards, like patents, might generate losses from the rush to be first. Creators might rush their standards to market, even where waiting would produce a better and more profitable product.

[9] Coase (1960). This paper is one of the most influential economics articles of the century. Coase pointed out that what may appear to be externalities often will be taken care of in the market.

inertia is apt to be very hard to find. Observable instances in which a dramatically inferior standard prevails are likely to be short-lived, imposed by authority, or fictional.

The creator of a standard is a natural candidate to internalize the externality.[10] If a standard can be "owned," the advantage of the standard can be appropriated, at least in part, by the owner. Dvorak, for example, patented his keyboard. An owner with the prospect of appropriating substantial benefits from a new standard would have an incentive to share some of the costs of switching to a new standard. This incentive gives rise to a variety of internalizing tactics. Manufacturers of new products sometimes offer substantial discounts to early adopters, offer guarantees of satisfaction, or make products available on a rental basis. Sometimes manufacturers offer rebates to buyers who turn in equipment based on old standards, thus discriminating in price between those who have already made investments in a standard and those who have not. Internalizing tactics can be very simple: some public utilities once supplied light bulbs, and some UHF television stations still offer free UHF indoor antennas. In many industries firms provide subsidized or free training to assure an adequate supply of operators. Typewriter manufacturers were an important source of trained typists for at least the first fifty years of that technology.[11]

Another internalizing tactic is convertibility. Suppliers of new-generation computers occasionally offer a service to convert files to new formats. Cable-television companies have offered hardware and services to adapt old televisions to new antenna systems for an interim period. Of interest in the present context, for a time before and after the Second World War, typewriter manufacturers offered to convert QWERTY typewriters to Dvorak for a very small

[10] We may ask ourselves why new standards are created if not with the idea of some pecuniary reward One would hardly expect nonobvious and costly standards to proliferate like manna from heaven.

fee.**12**

All of these tactics tend to unravel the apparent trap of an inefficient standard, but there are additional conditions that can contribute to the ascendancy of the efficient standard. An important one is the growth of the activity that uses the standard. If a market is growing rapidly the number of users who have made commitments to any standard is small relative to the number of future users. Sales of audiocassette players were barely hindered by their incompatibility with the reel-to-reel or eight-track players that preceded them. Sales of sixteen-bit computers were scarcely hampered by their incompatibility with the disks or operating systems of eight-bit computers.

Another factor that must be addressed is the initial competition among rival standards. If standards are chosen largely through the influence of those who are able to internalize the value of standards we would expect in Darwinian fashion the prevailing standard to be the fittest economic competitor. Previous keyboard histories have acknowledged the presence of rivals but they seem to view competition as a process leading to results indistinguishable from pure chance.

Consideration of the many complicating factors present in the market suggests that market failure in standards is not as compelling as many of the abstract models seem to suggest. Theoretical abstraction presents candidates for what might be important, but only empirical verification can determine if these abstract models have anything to do with reality.

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[11] Herkimer County Historical Society, (l923), which notes that in the early 1920's a single typewriter company was producing 100,000 typists a year.

12 Foulke (1961) notes on page 106: "Present day keyboard machines may be converted to the simplified Dvorak keyboard in local typewriter shops. It is now available on any typewriter. And it costs as little as $5 to convert a Standard to a simplified keyboard."

C. The Case For The Superiority Of The Dvorak Keyboard

Paul David, a leading economic historian, with his 1985 paper introduced economists to the conventional story of the development and persistence of the current keyboard standard, known as the Universal, or QWERTY, keyboard. The key features of that story are as follows. The operative patent for the typewriter was awarded in 1868 to Christopher Latham Sholes, who continued to develop the machine for several years. Among the problems that Sholes and his associates addressed was the jamming of the type bars when certain combinations of keys were struck in very close succession. As a partial solution to this problem, Sholes arranged his keyboard so that the keys most likely to be struck in close succession approached the type point from opposite sides of the machine. Since QWERTY was designed to accomplish this now obsolete mechanical requirement, maximizing speed was not an explicit objective. Some authors even claim that the keyboard is actually configured to minimize speed since decreasing speed would have been one way to avoid the jamming of the typewriter. At the time, however, a two-finger hunt-and-peck method was probably all that was contemplated, so the keyboard speed envisioned was quite different from touch-typing speeds.

The rights to the Sholes patent were sold to E. Remington & Sons in early 1873. The Remingtons added further mechanical improvements and began commercial production in late 1873.

A watershed event in the received version of the QWERTY story is a typing contest held in Cincinnati on July 25, 1888. Frank McGurrin, a court stenographer from Salt Lake City, who was apparently one of the first typists to memorize the keyboard and use touch-typing, won a decisive victory over Louis Taub. Taub used the hunt-and-peck method on a Caligraph, a machine that used seventy-two keys to provide upper- and lower-case letters. According to

popular history, the event established once and for all that the Remington typewriter, with its QWERTY keyboard, was technically superior. More important, the contest created an interest in touch-typing, an interest directed at the QWERTY arrangement. Reportedly, no one else at that time had skills that could even approach McGurrin's, so there was no possibility of countering the claim that the Remington keyboard arrangement was efficient. McGurrin participated in typing contests and demonstrations throughout the country and became something of a celebrity. His choice of the Remington keyboard, which may well have been arbitrary, contributed to the establishment of the standard. So it was, according to the popular telling, that a keyboard designed to solve a short-lived mechanical problem became the standard used daily by millions of typists.**13**

In 1936, August Dvorak patented the Dvorak Simplified Keyboard (DSK), claiming that it dramatically reduced the finger movement necessary for typing by balancing the load between hands and loading the stronger fingers more heavily. Its inventors claimed advantages of greater speed, reduced fatigue, and easier learning. These claims have been accepted by most commentators including David who refers, without citation, to experiments done by the U.S. Navy that had shown that the increased efficiency obtained with the DSK would amortize the cost of retraining a group of typists within ten days of their subsequent full-time employment.**14** In spite of its claimed advantages the Dvorak keyboard has never found much acceptance.

This story is the basis of the claim that the current use of the QWERTY keyboard is a market failure. The claim continues that a beginning typist will not choose to train in Dvorak

13 This history follows David (1985) but see Beeching (1974) as an example of an account with the features and emphasis described here.

14 David (1985) at 332. If true, this would be quite remarkable. A converted Sholes typist will be typing so much faster that whatever the training cost it is repaid every ten days. Counting only working days this would imply that the investment in

because Dvorak machines are likely to be difficult to find, and offices will not equip with Dvorak machines because there is no available pool of typists.

This is an ideal example. The number of dimensions of performance are few and in these dimensions the Dvorak keyboard appears overwhelmingly superior. These very attributes imply, however, that the forces to adopt this superior standard should also be very strong. It is the failure of these forces to prevail that warrants our critical examination.

D. The Myth of Dvorak

Farrell and Saloner mention the typewriter keyboard as a clear example of market failure. So too does the textbook by Tirole.**15** Both works cite David's article as the authority on this subject. Yet there are many aspects of the QWERTY-versus-Dvorak fable that do not survive scrutiny. First, the support for the claim that Dvorak is a better keyboard is both scant and suspect. Second, studies in the ergonomics literature find no significant advantage for Dvorak that can be deemed scientifically reliable. Third, the competition among producers of typewriters, out of which the standard emerged, was far more vigorous than is commonly reported. Fourth, there were far more typing contests than just the single Cincinnati contest. These contests provided ample opportunity to demonstrate the superiority of alternative keyboard arrangements. That QWERTY survived significant challenges early in the history of typewriting demonstrates that it is at least among the reasonably fit, even if not the fittest that can be imagined.

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retraining repays itself approximately twenty-three times in a year. Does this seem even remotely possible? Do firms typically ignore investments with returns in the range of 2200 percent?

15 Tirole, at 405. states: "Many observers believe that the Dvorak keyboard is superior to this QWERTY standard even when retraining costs are taken into account. However it would be foolish for a firm to build this alternative keyboard and for secretaries to switch to it individually". Under some circumstances it might have been foolish for secretaries and firms to act in this manner but this type of behavior hardly seems foolish in many real-world situations For example, large organizations

1. Gaps In The Evidence For Dvorak

Like most of the historians of the typewriter, David seems to assume that Dvorak is decisively superior to QWERTY. He never questions this assertion, and he consistently refers to the QWERTY standard as inferior. His most tantalizing evidence is his undocumented account of the U.S. Navy experiments. After recounting the claims of the Navy study, he adds "if as Apple advertising copy says, DSK 'lets you type 20 to 40% faster,' why did this superior design meet essentially the same resistance as the previous seven improvements on the QWERTY typewriter keyboard?"[16]

Why indeed? The survival of QWERTY is surprising to economists only in the presence of a demonstrably superior rival. David uses QWERTY's survival to demonstrate the nature of path dependency, the importance of history for economists, and the inevitable oversimplification of reality imposed by theory. Numerous theorists have used his historical evidence to claim empirical relevance for their versions of market failure. But on what foundation does all this depend? All we get from David is an undocumented assertion and some advertising copy.

Although the view that Dvorak is superior is widely held, this view can be traced to a few key sources. A book published by Dvorak and several co-authors in 1936 included some of Dvorak's own scientific inquiry.[17] Dvorak and his co-authors compared the typing speed achieved in four different and completely separate experiments conducted by various researchers for various purposes.[18]

One of these experiments examined the typing speed on the Dvorak keyboard and three

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(federal, state, and local governments, Fortune 500 companies, etc., often have tens of thousands of employees. And these organizations could have undertaken the training if the costs really were compensated in a short time.

[16] David (1986) at page 34.

[17] Dvorak et. al., (1936).

[18] Page 226.

examined typing speed on the QWERTY keyboard. The authors claimed that these studies established that students learn Dvorak faster than they learn QWERTY. A serious criticism of their methodology is that the various studies they compared used students of different ages and abilities (for example students learning Dvorak in grades 7 and 8 at the University of Chicago Lab School were compared with students in conventional high schools), in different school systems taking different tests, and in classes that met for different periods of time. Still more serious is that they did not stipulate whether their choice of studies was a random sample or the full population of available studies. So their study really establishes only that it is possible to find studies in which students learning to type on QWERTY keyboards appear to have progressed less rapidly in terms of calendar time than Dvorak's students did on his keyboard. Even in this Dvorak study however the evidence is mixed as to whether students, as they progress, retain an advantage when using the Dvorak keyboard since the differences seem to diminish as typing speed increases.

In general it is desirable to have independent evaluation and here the objectivity of Dvorak and his co-authors seems particularly open to question. Their book seems to be more in the vein of an inspirational tract than a scientific work. Consider the following passages taken from their chapter about relative keyboard performances):

> The bare recital to you of a few simple facts should suffice to indict the available spatial pattern that is so complacently entitled the universal [QWERTY] keyboard. Since when was the universe lopsided? The facts will not be stressed, since you may finally surmount most of the ensuing handicaps of this [QWERTY] keyboard. Just enough facts will be paraded to lend you double assurance that for many of the errors that you will inevitably make and for much of the discouraging delay you will experience in longed-for speed gains, you are not to blame. If you grow indignant over the beginner's role of innocent victim, remember that a little emotion heightens determination.**19**

19 Page 210.

> Analysis of the present keyboard is so destructive that an improved arrangement is a modern imperative. Isn't it obvious that faster, more accurate, less fatiguing typing can be attained in much less learning time provided a simplified keyboard is taught. **20**

The Navy study, which seems to have been the basis for some of the more extravagant claims of Dvorak advocates, is also flawed. Arthur Foulke, Sholes's biographer, and a believer in the superiority of the Dvorak keyboard, points out several discrepancies in the reports coming out of the Navy studies. He cites an Associated Press report of October 7, 1943, to the effect that a new typewriter keyboard allowed typists to "zip along at 180 words per minute" but then adds 'However, the Navy Department, in a letter to the author October 14, 1943 by Lieutenant Commander W. Marvin McCarthy said that it had no record of and did not conduct such a speed test, and denied having made an official announcement to that effect."[21] Foulke also reports a *Business Week* story of October 16, 1943, that reports a speed of 108, not 180, words per minute.

We were able to obtain, with difficulty, a copy of the 1944 Navy report.**22** The report does not state who conducted the study. It consists of two parts, the first based on an experiment conducted in July of 1944 and the second based on an experiment conducted in October of that year. The report's foreword states that two prior experiments had been conducted but that "the first two groups were not truly fair tests." We are not told the results of the early tests.

The first of the reported experiments consisted of the retraining of fourteen Navy typists on newly overhauled Dvorak keyboards for two hours a day. We are not told how the subjects were

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20 Page 221.

[21] Foulke at page 103.

22 We tried to have the Navy supply us with a copy when our own research librarians could not find it. The Navy research librarian had no more success even though she checked the Navy records, the Martin Luther King Library, the Library of Congress, the National Archives, the National Technical Communication service, etc. We were finally able to locate a copy held by an organization, Dvorak International. We would like to thank its director, Virginia Russell, for her assistance. She believes that they obtained their copy from the Underwood Company. We would be more sanguine about the question of the document's history had it been available in a public archive The copy we received was "A Practical Experiment in Simplified Keyboard Retraining--a Report on the Retraining of Fourteen Standard Keyboard Typists on the Simplified Keyboard and a Comparison of Typist Improvement from Training on the standard Keyboard and Retraining on the Simplified Keyboard", Navy Department, Division of Shore Establishments and Civilian Personnel, Department of Services, Training Section, Washington. DC. (July and October 1944)

chosen, but it does not appear to be based on a random process. At least twelve of these individuals had previously been QWERTY typists with an average speed of thirty-two words per minute although the Navy defined competence as fifty words per minute. The typists had IQs that averaged 98 and dexterity skills with an average percentile of 65. The study reports that it took fifty-two hours for typists to catch up to their old speed. After completing an average of eighty-three hours on the new keyboard, typing speed had increased to an average of fifty-six net words per minute compared to their original thirty-two words per minute, a 75 percent increase.

The second experiment consisted of the retraining of eighteen typists on the QWERTY keyboard. It is not clear how these typists were picked or even if members of this group were aware that they were part of an experiment. We are not told whether this training was performed in the same manner as the first experiment (the Navy retrained people from time to time and this may just have been one of these groups). The participants' IQs and dexterity skills are not reported. It is difficult to have any sense whether this group is a reasonable control for the first group. The initial typing scores for this group averaged twenty-nine words per minute but these scores were not measured identically to those from the first experiment. The report states that because three typists initially had net scores of zero words per minute, the beginning and ending speeds were calculated as the average of the first four typing tests and the average of the last four typing tests. In contrast, the initial experiment using Dvorak simply used the first and last test scores. This truncation of the reported values reduced the measured increase in typing speed on the QWERTY keyboard by a substantial margin and raises further suspicion upon the motives and abilities of the researchers.[23]

[23] It is not an innocuous change. We are told (at page 20) that three QWERTY typists initially scored zero on the typing test but that their scores rose to twenty-nine, thirteen, and sixteen within four days. We are also told that several other typists had similar improvements in the first four days. These improvements are dismissed as mere testing effects that the researchers wished to

The measured increase in net typing speed for QWERTY retraining was from twenty-nine to thirty-seven words per minute (28 percent) after an average of 158 hours of training, considerably less than the increase that occurred with the Dvorak keyboard.

The Navy study concludes that training in Dvorak is much more effective than retraining in QWERTY. But the experimental design leaves too many questions for this to be an acceptable finding. Do these results hold for typists with normal typing skills or only for those far below average? Were the results for the first group just a regression to the mean for a group of underperforming typists? How much did the Navy studies underestimate the value of increased QWERTY retraining due to the inconsistent measurement? Were the two groups given similar training? Were the QWERTY typewriters overhauled, as were the Dvorak typewriters? There are many possible biases in this study. All, suspiciously, seem to be in favor of the Dvorak design.

The authors of the Navy study do seem to have their minds made up concerning the superiority of Dvorak. In discussing the background of the Dvorak keyboard and prior to introducing the results of the study, the report claims on page 2: "Indisputably, it is obvious that the Simplified Keyboard is easier to master than the Standard Keyboard." Later, on page 24, the report's authors refer to QWERTY as an "ox" and Dvorak as a "jeep" and add: "no amount of goading the oxen can materially change the end result."

There are other problems of credibility with these Navy studies having to do with potential

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eliminate. But the researchers made no effort to eliminate the analogous testing effect for the Dvorak typists. Truncating the measurements to the average of the first four days reduces the reported speed increases for the three typists with zero initial speed by at least thirteen, twelve, and fourteen words per minute. Assuming the existence of two other typists with similar size testing effects, removing this testing effect would reduce the reported speed improvements by 3.6 words per minute lowering the gain from 46 percent to 28 percent. We are not supplied sufficient data to measure the effect of the truncation at the end of the measuring period. But the problem is worse than just this. Not only were the improvements measured differently, but truncation at this stage is entirely unjustified since there is no testing effect be removed at this stage of the experiment after many tests have been taken. While the apparent effect of these measurement differences is significant, the indisputable problem is that they were not applied equally to the QWERTY and Dvorak typists.

conflicts of interest. Foulke (at page 103) identifies Dvorak as Lieutenant Commander August Dvorak, the Navy's top expert in the analysis of time and motion studies during World War II. Earle Strong, a professor at Pennsylvania State University and a one-time chairman of the Office Machine Section of the American Standards Association, reports that the 1944 Navy experiment and some Treasury department experiments performed in 1946 were conducted by non other than Dr. Dvorak.[24] We also know that Dvorak had a financial stake in this keyboard. He owned the patent on the keyboard and had received at least $130,000 from the Carnegie Commission for Education for the studies performed while he was at the University of Washington.[25]

But there is more to this story than the weakness of the evidence reported by the Navy, or Dvorak, or his followers. A 1956 General Services Administration study by Earle Strong, which was influential in its time, provides the most compelling evidence against the Dvorak keyboard. This study is ignored in David's history for economists and is similarly ignored in other histories directed at general audiences. Strong conducted what appears to be a carefully controlled experiment designed to examine the costs and benefits of switching to Dvorak. He concluded that retraining typists on Dvorak had no advantages over retraining on QWERTY.

In the first phase of Strong's experiment, ten government typists were retrained on the Dvorak keyboard. It took well over twenty-five days of four-hour-a-day training sessions for these typists to catch up to their old QWERTY speed. When the typists had finally caught up to their old speed, Strong began the second phase of the experiment. The newly trained Dvorak

[24] Earle P. Strong (1956). Yamada (1980), trying to refute criticisms of Dvorak's keyboard, claims that Dvorak did not conduct these studies, but only provided the typewriters. Yamada admits that Dvorak was in the Navy and in Washington when the studies were conducted but denies any linkage. We do not know whom to believe, but we are skeptical that Dvorak would not have had a large influence on these tests, based on the strong circumstantial evidence and given Foulke's identification of Dvorak as the Navy's top expert on such matters. Interestingly, Yamada accuses Strong of being biased against the Dvorak keyboard (at 188). He also impugns Strong's character. He accuses Strong of refusing to provide other (unnamed) researchers with his data. He also implies that Strong stole money from Dvorak because in 1941, when Strong was a supporter of Dvorak's keyboard, he supposedly accepted payment from Dvorak to conduct a study of the DSK keyboard without ever reporting his results to him.

typists continued training and a group of ten QWERTY typists began a parallel program to improve their skills. In this second phase, the Dvorak typists progressed less quickly with further Dvorak training than did QWERTY typists training on QWERTY keyboards. Thus, Strong concluded that Dvorak training would never be able to amortize its costs. He recommended that the government provide further training in the QWERTY keyboard, for QWERTY typists. The information provided by this study was largely responsible for putting Dvorak to rest as a serious alternative to QWERTY for many firms and government agencies.[26]

Strong's study does leave some questions unanswered. Because it uses experienced typists it cannot tell us whether beginning Dvorak typists could be trained more quickly than beginning QWERTY typists. Further, although one implication of Strong's study is that the ultimate speed achieved would be greater for QWERTY typists than for Dvorak typists (since the QWERTY group was increasing the gap over the Dvorak group in the second phase of the experiment), we cannot be sure that an experiment with beginning typists would provide the same results.[27]

Nevertheless, Strong's study must be taken seriously. It attempts to control the quality of the two groups of typists and the instruction they receive. It directly addresses the claims that came out of the Navy studies, which consider the costs and benefits of retraining. It directly parallels the decision that a real firm or a real government agency might face: is it worthwhile to retrain its present typists? The alleged market failure of the QWERTY keyboard as represented by Farrell and Saloner's excess inertia notion is that all firms would change to a new standard if only they

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[25] Yamada (1980).

[26] At the time of Strong s experiment Dvorak had attracted a good deal of attention. At least one trade group had taken the position that pending confirmation from the Strong study it would adopt Dvorak as its new standard. See 'US plans to test New Typewriter', New York Times, November 1, 1955; 'Revolution in the Office', New York Times, November 30 1955; 'Key Changes Debated', New York Times, June 18, 1956; 'US. Balks at Teaching Old Typists New Keys', New York Times, July 2, 1956; and Peter White, 'Pyfgcrt vs. Qwertyuiop', New York Times, January 22 1956, at 18.

[27] In fact, both the Navy and General Service Administration studies found that the best typists take the longest time to catch up to their old speed and showed the smallest percentage improvement with retraining.

could each be assured that the others would change. If we accept Strong's findings, it is not a failure to communicate that keeps firms from retraining its typists or keeps typists from incurring their own retraining costs. If Strong's study is correct, it is efficient for current typists not to switch to Dvorak.

Current proponents of Dvorak have a different view when they assess why the keyboard has not been more successful. Hisao Yamada, an advocate of Dvorak who is attempting to influence Japanese keyboard development, gives a wide-ranging interpretation to the Dvorak keyboard's failure. He blames the Depression, bad business decisions by Dvorak, World War II, and the Strong report. He goes on to say:

> There were always those who questioned the claims made by DSK followers. Their reasons are also manifold. Some suspected the superiority of the instructions by DSK advocates to be responsible (because they were all holders of advanced degrees); such a credential of instructors is also apt to cause the Hawthorne effect. Others maintain that all training experiments, except the GSA one as noted, were conducted by the DSK followers, and that the statistical control of experiments was not well exercised. This may be a valid point. It does not take too long to realize, however, that it is a major financial undertaking to organize such an experiment to the satisfaction of statisticians.... The fact that those critics were also reluctant to come forth in support of such experiments . . . may indicate that the true reason of their criticism lies elsewhere.[28]

Nevertheless, Yamada as much as admits that experimental findings reported by Dvorak and his supporters cannot be assigned much credibility and that the most compelling claims cited by Yamada for DSK's superiority come from Dvorak's own work. Much of the other evidence Yamada uses to support his views of DSK's superiority actually can be used to make a case against Dvorak. Yamada refers to a 1952 Australian post office study that showed no advantages for DSK when it was first conducted. It was only after adjustments were made in the test procedure (to remove 'psychological impediments to superior performance') that DSK did

[28] Yamada at 189.

better.**29** He cites a 1973 study based on six typists at Western Electric where after 104 hours of training on DSK, typists were 2.6 percent faster than they had been on QWERTY.**30** Similarly, Yamada reports that in a 1978 study at Oregon State University after 100 hours of training typists were up to 97.6 percent of their old QWERTY speed. Both of these retraining times are similar to those reported by Strong and not to those in the Navy study. Yamada, however, thinks the studies themselves support Dvorak.[31] But unlike the Strong study, neither of these studies included parallel retraining on QWERTY keyboards. As the Strong study points out, even experienced QWERTY typists increase their speed on QWERTY if they are given additional training. Even if that problem is ignored the possible advantages of Dvorak are all much weaker than those reported from the Navy study.

2. Evidence From The Ergonomics Literature

The most recent studies of the relative merits of keyboards are found in the ergonomics literature. These studies provide evidence that the advantage of the Dvorak layout is either small or nonexistent. For example, A. Miller and J. C. Thomas conclude that "the fact remains, however, that no alternative has shown a realistically significant advantage over the QWERTY for general purpose typing."**32** In two studies based on analysis of hand-and-finger motions R. F. Nickells Jr. finds that Dvorak is 6.2 percent faster than QWERTY,**33** and R. Kinkhead finds only a 2.3 percent advantage for Dvorak.**34** Simulation studies by Donald Norman and David Rumelhart find similar results:

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29 Yamada at 185.
30 Yamada at 188.
[31] Yamada interprets the Oregon study to support the Dvorak keyboard. To do so he fits an exponential function to the Oregon data and notes that the limit of the function as hours of training goes to infinity is 17 percent greater than the typist's initial QWERTY speed. This function is extremely flat, however, and even modest gains appear well outside the range of the data. A 10 percent gain, for example, would be projected to occur only after 165 hours of training .
32 A. Miller & J. C. Thomas, Behavioral Issues in the Use of interactive Systems, 9 Int. J. of Man-Machine Stud. 509 (l977).
33 Cited in Hisao Yamada, Certain Problems Associated with the Design of input Key-boards for Japanese Writing, in Cognitive Aspects of Skilled Typewriting 336 (William E. Cooper ed. 1983).

> In our studies . . . we examined novices typing on several different arrangements of alphabetically organized keyboards, the Sholes (QWERTY) keyboard, and a randomly organized keyboard to control against prior knowledge of Sholes). There were essentially no differences among the alphabetic and random keyboards. Novices type slightly faster on the Sholes keyboard, probably reflecting prior experience with it. We studied expert typists by using our simulation model. Here, we looked at the Sholes and Dvorak layouts, as well as several alphabetically arranged keyboards. The simulation showed that the alphabetically organized keyboards were between 2% and 9% slower than the Sholes keyboard, and the Dvorak keyboard was only about 5% faster than the Sholes. These figures correspond well to other experimental studies that compared the Dvorak and Sholes keyboards and to the computations of Card, Moran, and Newell . . . for comparing these keyboards.... For the expert typist, the layout of keys makes surprisingly little difference. There seems no reason to choose Sholes, Dvorak. or alphabetically organized keyboards over one another on the basis of typing speed. It is possible to make a bad keyboard layout, however, and two of the arrangements that we studied can be ruled out.**35**

These ergonomic studies are particularly interesting because the claimed advantage of the Dvorak keyboard has been based historically on the claimed ergonomic advantages in reduced finger movement. Norman and Rummelhart's discussion offers clues to why Dvorak does not provide as much of an advantage as its proponents have claimed. They argue,

> For optimal typing speed. keyboards should be designed so that:
>
> A. The loads on the right and left hands are equalized.
>
> B. The load on the home (middle) row is maximized.
>
> C. The frequency of alternating hand sequences is maximized and the frequency of same-finger typing is minimized.
>
> The Dvorak keyboard does a good job on these variables, especially A and B: 67% of the typing is done on the home row and the left-right hand balance is 47-53%. Although the Sholes (QWERTY) keyboard fails at conditions A and B (most typing is done on the top row and the balance between the two hands is 57% and 43%), the policy to put successively typed keys as far apart as possible favors factor C, thus leading to relatively rapid typing.

The explanation for Norman and Rummelhart's factor C is that during a keystroke, the idle hand prepares for its next keystroke. Thus, Sholes's decision to solve a mechanical problem through careful keyboard arrangement may have inadvertently satisfied a fairly important requirement for efficient typing.

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34 Cited in Yamada. at 365.
35 Norman and Rumelhart (1983).

The consistent finding in the ergonomic studies is that the results imply no clear advantage for Dvorak. These studies are not explicitly statistical, yet their negative claim seems analogous to the scientific caution that one exercises when measured differences are small relative to unexplained variance. We read these authors as saying that, in light of the imprecision of method, scientific caution precludes rejection of the hypothesis that Dvorak and QWERTY are equivalent. At the very least, the studies indicate that the speed advantage of Dvorak is not anything like the 20-40 percent that is claimed in the Apple advertising copy cited by David. Moreover, the studies suggest that there may be no advantage with the Dvorak keyboard for ordinary typing by skilled typists. It appears that the principles by which Dvorak "rationalized" the keyboard may not have fully captured the actions of experienced typists largely because typing appears to be a fairly complex activity.

A final word on all of this comes from Frank McGurrin, the world's first known touch-typist:

> Let an operator take a new sentence and see how fast he can write it. Then, after practicing the sentence, time himself again, and he will find he can write it much faster: and further practice on the particular sentence will increase the speed on it to nearly or quite double that on the new matter. Now let the operator take another new sentence, and he will find his speed has dropped back to about what it was before he commenced practicing the first sentence. Why is this? The fingers are capable of the same rapidity. It is because the mind is not so familiar with the keys.**36**

Of course, performance in any physical activity can presumably be improved with practice. But the limitations of typing speed, in McGurrin's experiment, appear to have something to do with a mental or, at least, neurological skill and fairly little to do with the limitations on the speeds at which the fingers can complete their required motions.

36 George C. Mares. The History of the Typewriter (1909).

3. Typewriter Competition

The Sholes typewriter was not invented from whole cloth. Yamada reports that there were fifty-one inventors of prior typewriters, including some earlier commercially produced typewriters. He states: "Examination of these materials reveals that almost all ideas incorporated into Sholes' machines, if not all, were at one time or another already used by his predecessors."**37**

Remington's early commercial rivals were numerous, offered substantial variations on the typewriter, and in some cases enjoyed moderate success. There were plenty of competitors after the Sholes machine came to market. The largest and most important of these rivals were the Hall, Caligraph, and Crandall machines. The Yost, another double-keyboard machine, manufactured by an early collaborator of Sholes, used a different inking system and was known particularly for its attractive type. According to production data assembled by Yamada, the machines were close rivals, and they each sold in large numbers.**38** Franz Xavier Wagner, who also worked on the 1873 Remington typewriter, developed a machine that made the type fully visible as it was being typed. This machine was offered to, but rejected by, the Union Typewriter Company, the company formed by the 1893 merger of Remington with six other typewriter manufacturers.**39** In 1895, Wagner joined John T. Underwood to produce his machine. Their company, which later became Underwood, enjoyed rapid growth, producing two hundred typewriters per week by 1898.**40** Wagner's offer to Union also resulted in the spin-off from Union of L. C. Smith, who introduced a visible-type machine in 1904.[41] This firm was the forerunner of the Smith-Corona company.

37 Yamada at 177.
38 Yamada at 181.
39 Beeching, at 165.
40 Beeching at 214.

Two manufacturers offered their own versions of an ideal keyboard: Hammond in 1893 and Blickensderfer in 1889.[42] Each of these machines survived for a time, and each had certain mechanical advantages. Blickensderfer later produced what may have been the first portable and the first electric typewriters. Hammond later produced the Varityper, a standard office type-composing machine that was the antecedent of today's desktop publishing. The alternative keyboard machines produced by these manufacturers came early enough that typewriters and, more important, touch-typing were still not very popular. The Blickensderfer appeared within a year of the famous Cincinnati contest that first publicized touch-typing.

In the 1880s and 1890s typewriters were generally sold to offices not already staffed with typists or into markets in which typists were not readily available. Since the sale of a new machine usually meant training a new typist, a manufacturer that chose to compete using an alternative keyboard had an opportunity. As late as 1923, typewriter manufacturers operated placement services for typists and were an important source of operators. In the earliest days, typewriter salesmen provided much of the limited training available to typists.[43] Since almost every sale required the training of a typist, a typewriter manufacturer that offered a different keyboard was not particularly disadvantaged. Manufacturers internalized training costs in such an environment, so a keyboard that allowed more rapid training might have been particularly attractive.

Offering alternative keyboards was not a terribly expensive tactic. The Blickensderfer used a type-bar configuration similar in principle to the IBM Selectric type ball and, so, could easily

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41 Beeching at 165.

42 David (1986) at 38. Also see Beeching at 40, 199. Yamada, at 184. in discussing the Hammond keyboard arrangement states: "This 'ideal' arrangement was far better than QWERTY but it did not take root because by then Remington Schools were already turning out a large number of QWERTY typists every year." In 1893, Blickensderfer offered a portable typewriter with the Hammond keyboard.

offer many different configurations. The others could create alternative keyboard arrangements by simply soldering the type to different bars and attaching the keys to different levers. So apparently the problem of implementing the conversion was not what kept the manufacturers from changing keyboards.

The rival keyboards did ultimately fail, of course.[44] But the QWERTY keyboard cannot have been so well established at the time the rival keyboards were first offered that they were rejected because they were non-standard. Manufacturers of typewriters sought and promoted any technical feature that might give them an advantage in the market. Certainly, shorter training and greater speed would have been an attractive selling point for a typewriter with an alternative keyboard. Neither can it be said that the rival keyboards were doomed by inferior mechanical characteristics because these companies went on to produce successful and innovative, though QWERTY-based, typing machines. Thus we cannot attribute our inheritance of the QWERTY keyboard to a lack of alternative keyboards or the chance association of this keyboard arrangement with the only mechanically adequate typewriter.

4. Typing Competitions

Typing competitions provided another test of the QWERTY keyboard. These competitions are somewhat underplayed in the conventional history. David's history mentions only the Cincinnati contest. Wilfred Beeching's history, which has been very influential, also mentions only the Cincinnati contest and attaches great importance to it: "Suddenly, to their horror, it dawned upon both the Remington Company and the Caligraph company officials, torn between

43 Herkimer County Historical Society, at 78.

44 We should also take note of the fact that the QWERTY keyboard, although invented in the United States. has become the dominant keyboard throughout the world. Foreign countries, when introduced to typewriters, need not have adopted this keyboard if superior alternatives existed since there would not yet have been any typists trained on QWERTY. Yet all other keyboard designs fell before the QWERTY juggernaut. In France and some other countries, the keyboard is slightly different than

pride and despair, that whoever won was likely to put the other out of business!" Beeching refers to the contest as having established the four-bank keyboard of the Remington machine "once and for all."[45]

In fact, typing contests and demonstrations of speed were fairly common during this period. They involved many different machines, with various manufacturers claiming to hold the speed record.

Under the headline "Wonderful Typing," the *New York Times* reported on a typing demonstration given the previous day in Brooklyn by a Mr. Thomas Osborne of Rochester, New York.[46] The Times reported that Mr. Osborne "holds the championship for fast typing, having accomplished 126 words a minute at Toronto August 13 last." This was a mere three weeks after the Cincinnati contest. In the Brooklyn demonstration he typed 142 words per minute in a five-minute test, 179 words per minute in a single minute. and 198 words per minute for 30 seconds. He was accompanied by a Mr. George McBride, who typed 129 words per minute blindfolded. Both men used the non-QWERTY Caligraph machine. The *Times* offered that "the Caligraph people have chosen a very pleasant and effective way of proving not only the superior speed of their machine, but the falsity of reports widely published that writing blindfolded was not feasible on that instrument.

There were other contests and a good number of victories for McGurrin and Remington. On August 2, 1888, a mere week after the Cincinnati contest, the *Times* reported a New York contest won by McGurrin with a speed of 95.8 words per minute in a five-minute dictation. In light of

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the QWERTY keyboard used in the United states The major difference is that the top left-hand keys are Azerty (that is also what these keyboard designs are called) and several letters are transposed, but most of the keys are identical .

45 Beeching at 41.

46 New York Times, February 28, 1889 at 8.

the received history, according to which McGurrin is the only person to have memorized the keyboard, it is interesting to note the strong performance of his rivals. Miss May Orr typed 95.2 words per minute, and M. C. Grant typed 93.8 words per minute. Again, on January 9, 1889, the *Times* reported a McGurrin victory under the headline "Remington Still Leads the List."

We should probably avoid the temptation to compare the Caligraph speed with the Remington speeds, given the likely absence of any serious attempts at standardizing the tests. Nevertheless, it appears that the issue of speed was not so readily conceded as is reported in Beeching's history. Typists other than McGurrin could touch-type, and machines other than Remington were competitive. History has largely ignored events that did not build toward the eventual domination by QWERTY. This focus may be reasonable for the history of the Remington Company or the QWERTY keyboard. But if we are interested in whether the QWERTY keyboard's existence can be attributed to more than happenstance or an inventor's whim, these events do matter.

E. Conclusions

The trap constituted by an obsolete standard may be quite fragile. Because real-world situations present opportunities for agents to profit from changing to a superior standard, we cannot simply rely on an abstract model to conclude that an inferior standard has persisted. Such a claim demands empirical examination.

As an empirical example of market failure, the typewriter keyboard has much appeal. The objective of the keyboard is fairly straightforward: to get words onto the recording medium. There are no conflicting objectives to complicate the interpretation of performance. But the evidence in the standard history of QWERTY versus Dvorak is flawed and incomplete. First, the

claims for the superiority of the Dvorak keyboard are suspect. The most dramatic claims are traceable to Dvorak himself, and the best-documented experiments, as well as recent ergonomic studies, suggest little or no advantage for the Dvorak keyboard.[47]

Second, by ignoring the vitality and variety of the rivals to the Remington machine with its QWERTY keyboard, the received history implies that Sholes's and McGurrin's choices, made largely as matters of immediate expediency, established the standard without ever being tested. A more careful reading of historical accounts and checks of original sources reveal a different picture: there were touch-typists other than McGurrin; there were competing claims of speed records; and Remington was not so well established that a keyboard offering significant advantages could not have gained a foothold. If the fable is to carry lessons about the workings of markets, we need to know more than just who won. The victory of the tortoise is a different story without the hare.

There is more to this disagreement than a difference in the evidence that was revealed by our search of the historical record. Our reading of this history reflects a more fundamental difference in views of how markets, and social systems more generally, function. David's overriding point is that economic theory must be informed by events in the world. On that we could not agree more strongly. But ironically, or perhaps inevitably, David's interpretation of the historical record is dominated by his own implicit model of markets, a model that seems to underlie much

[47] There are several versions of the claim that a switch to Dvorak would not be worthwhile. The strongest, which we do not make, is that QWERTY is proven to be the best imaginable keyboard. Neither can we claim that Dvorak is proven to be inferior to QWERTY. Our claim is that there is no scientifically acceptable evidence that Dvorak offers any real advantage over QWERTY. Because of this claim, our assessment of a market failure in this case is rather simple. It might have been more complicated. For example, if Dvorak were found to be superior, it might still be the case that the total social benefits are less than the cost of switching. In that case, we could look for market failure only in the process that started us on the QWERTY keyboard (if the alternative were available at the beginning). Or we might have concluded that Dvorak is better and that all parties could be made better off if we could costlessly command both a switch and any necessary redistribution. Such a finding would constitute a market failure in the sense of mainstream welfare economics. Of course, this circumstance still might not constitute a market failure in the sense of Demsetz, which requires consideration of the costs of feasible institutions that could effect the change.

economic thinking. In that model an exogenous set of goods is offered for sale at a price, take it or leave it. There is little or no role for entrepreneurs. There generally are no guarantees, no rental markets, no mergers, no loss-leader pricing, no advertising, no marketing research. When such complicating institutions are acknowledged, they are incorporated into the model piecemeal. And they are most often introduced to show their potential to create inefficiencies, not to show how an excess of benefit over cost may constitute an opportunity for private gain.

In the world created by such a sterile model of competition, it is not surprising that accidents have considerable permanence. In such a world, embarking on some wrong path provides little chance to jump to an alternative path. The individual benefits of correcting a mistake are too small to make correction worthwhile, and there are no agents who might profit by devising some means of capturing a part of the aggregate benefits of correction.

It is also not surprising that in such a world there are a lot of accidents. Consumers are given very little discretion to avoid starts down wrong paths. A model may assume that consumers have foresight or even that they are perfectly rational, but usually in a very limited sense. For example, in the model of Farrell and Saloner, consumers can predict very well the equilibrium among the two candidate standards. But they are attributed no ability to anticipate the existence of some future, better standard. We are not led to ask how the incumbent standard achieved its status; as in David's reprise of Twain, "It jes' growed."

But at some moment, users must commit resources to a standard or wait. At this moment, they have clear incentives to examine the characteristics of competing standards. They must suffer the consequences of a decision to wait, to discard obsolete equipment or skills, or to continue to function with an inferior standard. Thus, they have a clear incentive to consider what

lies down alternative paths. Though their ability to anticipate future events may not be perfect, there is no reason to assume that their judgements are any more faulty than those of any other observers and there are reasons to believe their judgements are likely to be better.

Finally, it is consistent that, in a world in which mistakes are frequent and permanent, "scientific approaches" cannot help but make big improvements to market outcomes. In such a world, there is ample room for enlightened reasoning, personified by university professors, to improve on the consequences of myriad independent decisions. What credence can possibly be given to a keyboard that has nothing to accredit it but the trials of a group of mechanics and its adoption by millions of typists? If we use only sterilized models of markets, or ignore the vitality of the rivalry that confronts institutions, we should not be surprised that the historical interpretations that result are not graced with truth.