Clio and the Economics of QWERTY

By Paul A. David*

Cicero demands of historians, first, that we tell true stories. I intend fully to perform my duty on this occasion, by giving you a homely piece of narrative economic history in which "one damn thing follows another." The main point of the story will become plain enough: it is sometimes not possible to uncover the logic (or illogic) of the world around us except by understanding how it got that way. A *path-dependent* sequence of economic changes is one of which important influences upon the eventual outcome can be exerted by temporally remote events, including happenings dominated by chance elements rather than systematic forces. Stochastic processes like that do not converge automatically to a fixed-point distribution of outcomes, and are called *non-ergodic*. In such circumstances "historical accidents" can neither be ignored, nor neatly quarantined for the purpose of economic analysis; the dynamic process itself takes on an *essentially historical* character. Standing alone, my story will be simply illustrative and does not establish how much of the world works this way. That is an open empirical issue and I would be presumptuous to claim to have settled it, or to instruct you in what to do about it. Let us just hope the tale proves mildly diverting for those waiting to be told if and why the study of economic history is a necessity in the making of economists.

*Department of Economics, Encina Hall, Stanford University, Stanford, CA 94305. Support provided for this research, under a grant to the Technological Innovation Program of the Center for Economic Policy Research, Stanford University, is gratefully acknowledged. Douglas Puffert supplied able research assistance. Some, but not the whole, of my indebtedness to Brian Arthur's views on QWERTY and QWERTY-like subjects is recorded in the References. I bear full responsibility for errors of fact and interpretation, as well as for the peculiar opinions abbreviated herein. A fuller version with complete references, entitled "Understanding the Economics of QWERTY or Is History Necessary?," is available on request.

I. The Story of QWERTY

Why does the topmost row of letters on your personal computer keyboard spell out QWERTYUIOP, rather than something else? We know that nothing in the engineering of computer terminals requires the awkward keyboard layout known today as "QWERTY," and we all are old enough to remember that QWERTY somehow has been handed down to us from the Age of Typewriters. Clearly nobody has been persuaded by the exhortations to discard QWERTY, which apostles of DSK (the Dvorak Simplified Keyboard) were issuing in trade publications such as *Computers and Automation* during the early 1970's. Why not? Devotees of the keyboard arrangement patented in 1932 by August Dvorak and W. L. Dealey have long held most of the world's records for speed typing. Moreover, during the 1940's U.S. Navy experiments had shown that the increased efficiency obtained with DSK would amortize the cost of retraining a group of typists within the first ten days of their subsequent full-time employment. Dvorak's death in 1975 released him from forty years of frustration with the world's stubborn rejection of his contribution; it came too soon for him to be solaced by the Apple IIC computer's built-in switch, which instantly converts its keyboard from QWERTY to virtual DSK, or to be further aggravated by doubts that the switch would not often be flicked.

If as Apple advertising copy now says, DSK "lets you type 20–40% faster," why did this superior design meet essentially the same rejection as the previous seven improvements on the QWERTY typewriter keyboard that were patented in the United States and Britain during the years 1909–24? Was it the result of customary, nonrational behavior by countless individuals socialized to carry on an antiquated technological tradition? Or, as Dvorak himself once suggested, had there been a conspiracy among the members of the typewriter oligopoly to suppress an invention which they feared would so increase typewriter efficiency as ultimately to curtail the demand for their products? Or perhaps we should turn instead to the other popular "Devil Theory," and ask if political regulation and interference with the workings of the "free market" has been the cause of inefficient keyboard regimentation? Maybe it's all to be blamed on the public school system, like everything else that's awry?

You can already sense that these will not be the most promising lines along which to search for an economic understanding of QWERTY's present dominance. The agents engaged in production and purchase decisions in today's keyboard market are not the prisoners of custom, conspiracy, or state control. But while they are, as we now say, perfectly "free to choose," their behavior, nevertheless, is held fast in the grip of events long forgotten and shaped by circumstances in which neither they nor their interests figured. Like the great men of whom Tolstoy wrote in *War and Peace*, "(e) very action of theirs, that seems to them an act of their own free will, is in an historical sense not free at all, but in bondage to the whole course of previous history..." (Bk. IX, ch. 1).

This is a short story, however. So it begins only little more than a century ago, with the fifty-second man to invent the typewriter. Christopher Latham Sholes was a Milwaukee, Wisconsin printer by trade, and a mechanical tinkerer by inclination. Helped by his friends, Carlos Glidden and Samuel W. Soule, he had built a primitive writing machine for which a patent application was filed in October 1867. Many defects in the working of Sholes' "Type Writer" stood in the way of its immediate commercial introduction. Because the printing point was located underneath the paper carriage, it was quite invisible to the operator. "Non-visibility" remained an unfortunate feature of this and other up-stroke machines long after the flat paper carriage of the original design had been supplanted by arrangements closely resembling the modern continuous roller-platen. Consequently, the tendency of the typebars to clash and jam if struck in rapid succession was a particularly serious defect. When a typebar stuck at or near the printing point, every succeeding stroke merely hammered the same impression onto the paper, resulting in a string of repeated letters that would be discovered only when the typist bothered to raise the carriage to inspect what had been printed.

Urged onward by the bullying optimism of James Densmore, the promoter-venture capitalist whom he had taken into the partnership in 1867, Sholes struggled for the next six years to perfect "the machine." From the inventor's trial-and-error rearrangements of the original model's alphabetical key ordering, in an effort to reduce the frequency of typebar clashes, there emerged a four-row, upper case keyboard approaching the modern QWERTY standard. In March 1873, Densmore succeeded in placing the manufacturing rights for the substantially transformed Sholes-Glidden "Type Writer" with E. Remington and Sons, the famous arms makers. Within the next few months QWERTY's evolution was virtually completed by Remington's mechanics. Their many modifications included some fine-tuning of the keyboard design in the course of which the "*R*" wound up in the place previously allotted to the period mark "." Thus were assembled into one row all the letters which a salesman would need to impress customers, by rapidly pecking out the brand name: TYPE WRITER

Despite this sales gimmick, the early commercial fortunes of the machine, with which chance had linked QWERTY's destiny remained terrifyingly precarious. The economic downturn of the 1870's was not the best of times in which to launch a novel piece of office equipment costing $125, and by 1878, when Remington brought out its Improved Model Two (equipped with carriage shift key), the whole enterprise was teetering on the edge of bankruptcy. Consequently, even though sales began to pick up pace with the lifting of the depression and annual typewriter production climbed to 1200 units in 1881, the market position which QWERTY had acquired during the course of its early career was far from deeply entrenched; the entire stock of QWERTYembodying machines in the United States could not have much exceeded 5000 when the decade of the 1880's opened.

Nor was its future much protected by any compelling technological necessities. For, there were ways to make a typewriter without the up-stroke typebar mechanism that had called forth the QWERTY adaptation, and rival designs were appearing on the American scene. Not only were there typebar machines with "down-stroke" and "front-stroke" actions that afforded a visible printing point; the problem of typebar clashes could be circumvented by dispensing with typebars entirely, as young Thomas Edison had done in his 1872 patent for an electric print-wheel device which later became the basis for teletype machines. Lucien Stephen Crandall, the inventor of the second typewriter to reach the American market (in 1879) arranged the type on a cylindrical sleeve: the sleeve was made to revolve to the required letter and come down onto the printing-point, locking in place for correct alignment. (So much for the "revolutionary" character of the IBM 72/82's "golf ball" design.) Freed from the legacy of typebars, commercially successful typewriters such as the Hammond and the Blickensderfer first sported a keyboard arrangement which was more sensible than QWERTY. Then so-called "Ideal" keyboard placed the sequence DHIATENSOR in the home row, these being ten letters with which one may compose over 70 percent of the words in the English language.

The typewriter boom beginning in the 1880's thus witnessed a rapid proliferation of competitive designs, manufacturing companies, and keyboard arrangements rivalling the Sholes-Remington QWERTY. Yet, by the middle of the next decade, just when it had become evident that any micro-technological rationale for QWERTY's dominance was being removed by the progress of typewriter engineering, the U.S. industry was rapidly moving towards the standard of an upright front-stroke machine with a four-row QWERTY keyboard that was referred to as "the Universal." During the period 1895–1905, the main producers of non-typebar machines fell into line by offering "the Universal" as an option in place of the Ideal keyboard.

II. Basic QWERTY-Nomics

To understand what had happened in the fateful interval of the 1890's, the economist must attend to the fact that typewriters were beginning to take their place as an element of a larger, rather complex system of production that was technically interrelated. In addition to the manufacturers and buyers of typewriting machines, this system involved typewriter operators and the variety of organizations (both private and public) that undertook to train people in such skills. Still more critical to the outcome was the fact that, in contrast to the hardware subsystems of which QWERTY or other keyboards were a part, the larger system of production was nobody's design. Rather like the proverbial Topsy, and much else in the history of economies besides, it "jes' growed."

The advent of "touch" typing, a distinct advance over the four-finger hunt-and-peck method, came late in the 1880's and was critical, because this innovation was from its inception adapted to the Remington's QWERTY keyboard. Touch typing gave rise to three features of the evolving production system which were crucially important in causing QWERTY to become "locked in" as the dominant keyboard arrangement. These features were *technical interrelatedness*, *economies of scale*, and *quasi-irreversibility* of investment. They constitute the basic ingredients of what might be called QWERTY-nomics.

Technical interrelatedness, or the need for system compatibility between keyboard "hardware" and the "software" represented by the touch typist's memory of a particular arrangement of the keys, meant that the expected present value of a typewriter as an instrument of production was dependent upon the availability of compatible software created by typists' decisions as to the kind of keyboard they should learn. Prior to the growth of the personal market for typewriters, the purchasers of the hardware typically were business firms and therefore distinct from the owners of typing skills. Few incentives existed at the time, or later, for any one business to invest in providing its employees with a form of general human capital which so readily could be taken elsewhere. (Notice that it was the wartime U.S. Navy, not your typical employer, that undertook the experiment of retraining typists on the Dvorak keyboard.) Nevertheless the purchase by a potential employer of a QWERTY keyboard conveyed a positive pecuniary externality to compatibly trained touch typists. To the degree to which this increased the likelihood that subsequent typists would choose to learn QWERTY, in preference to another method for which the stock of compatible hardware would not be so large, the overall user costs of a typewriting system based upon QWERTY (or any specific keyboard) would tend to *decrease* as it gained in acceptance relative to other systems. Essentially symmetrical conditions obtained in the market for instruction in touch typing.

These decreasing cost conditions—or *system scale economies*—had a number of consequences, among which undoubtedly the most important was the tendency for the process of intersystem competition to lead towards de facto standardization through the predominance of a single keyboard design. For analytical purposes, the matter can be simplified in the following way: suppose that buyers of typewriters uniformly were without inherent preferences concerning keyboards, and cared only about how the stock of touch typists was distributed among alternative specific keyboard styles. Suppose typists, on the other hand, were heterogeneous in their preferences for learning QWERTY-based "touch," as opposed to other methods, but attentive also to the way the stock of machines was distributed according to keyboard styles. Then imagine the members of this heterogenous population deciding in random order what kind of typing training to acquire. It may be seen that, with unbounded decreasing costs of selection, each stochastic decision in favor of QWERTY would raise the probability (but not guarantee) that the next selector would favor QWERTY. From the viewpoint of the formal theory of stochastic processes, what we are looking at now is equivalent to a generalized "Polya urn scheme." In a simple scheme of that kind, an urn containing balls of various colors is sampled with replacement, and every drawing of a ball of a specified color results in a second ball of the same color being returned to the urn; the probabilities that balls of specified colors will be added are therefore increasing (linear) functions of the proportions in which the respective colors are represented within the urn. A recent theorem due to W. Brian Arthur et al. (1983; 1985) allows us to say that when a generalized form of such a process (characterized by unbounded increasing returns) is extended indefinitely, the proportional share of one of the colors will, with probability one, converge to unity.

There may be many eligible candidates for supremacy, and from an *ex ante* vantage point we cannot say with corresponding certainty which among the contending colors —or rival keyboard arrangements—will be the one to gain eventual dominance. That part of the story is likely to be governed by "historical accidents," which is to say, by the particular sequencing of choices made close to the beginning of the process. It is there that essentially random, transient factors are most likely to exert great leverage, as has been shown neatly by Arthur's (1983) model of the dynamics of technological competition under increasing returns. Intuition suggests that if choices were made in a forward-looking way, rather than myopically on the basis of comparisons among the currently prevailing costs of different systems, the final outcome could be influenced strongly by expectations. A particular system could triumph over rivals merely because the purchasers of the software (and/or the hardware) expected that it would do so. This intuition seems to be supported by recent formal analyses by Michael Katz and Carl Shapiro (1983), and Ward Hanson (1984), of markets where purchasers of rival products benefit from externalities conditional upon the size of the compatible system or "network" with which they thereby become joined. Although the initial lead acquired by QWERTY through its association with the Remington was quantitatively very slender, when magnified by expectations it may well have been quite sufficient to guarantee that the industry eventually would lock in to a de facto QWERTY standard.

The occurrence of this "lock in" as early as the mid-1890's does appear to have owed something also to the high costs of software "conversion" and the resulting *quasi-irreversibility of investments* in specific touch-typing skills. Thus, as far as keyboard conversion costs were concerned, an important asymmetry had appeared between the software and the hardware components of the evolving system: the costs of typewriter software conversion were going up, whereas the costs of typewriter hardware conversion were coming down. While the novel, non-typebar technologies developed during the 1880's were freeing the keyboard from technical bondage to QWERTY, typewriter makers were by the same token freed from fixed-cost bondage to any particular keyboard arrangement. Non-QWERTY typewriter manufacturers seeking to expand market share could cheaply switch to achieve compatibility with the already existing stock of QWERTY-programmed typists, who could not. This, then, was a situation in which the precise details of timing in the developmental sequence had made it privately profitable in the short run to adapt machines to the habits of men (or to women, as was increasingly the case) rather than the other way around. And things have been that way ever since.

III. Message

In place of a moral, I want to leave you with a message of faith and qualified hope. The story of QWERTY is a rather intriguing one for economists. Despite the presence of the sort of externalities that standard static analysis tells us would interfere with the achievement of the socially optimal degree of system compatibility, competition in the absence of perfect futures markets drove the industry prematurely into standardization *on the wrong system*—where decentralized decision making subsequently has sufficed to hold it. Outcomes of this kind are not so exotic. For such things to happen seems only too possible in the presence of strong technical interrelatedness, scale economies, and irreversibilities due to learning and habituation. They come as no surprise to readers prepared by Thorstein Veblen's classic passages in *Germany and the Industrial Revolution* (1915), on the problem of Britain's undersized railway wagons and "the penalties of taking the lead" (see pp. 126–27); they may be painfully familiar to students who have been obliged to assimilate the details of deservedly less-renowned scribblings (see my 1971, 1975 studies) about the obstacles which ridge-and-furrow placed in the path of British farm mechanization, and the influence of remote events in nineteenth-century U.S. factor price history upon the subsequently emerging bias towards Hicks' labor-saving improvements in the production technology of certain branches of manufacturing.

I believe there are many more QWERTY worlds lying out there in the past, on the very edges of the modern economic analyst's tidy universe; worlds we do not yet fully perceive or understand, but whose influence, like that of dark stars, extends nonetheless to shape the visible orbits of our contemporary economic affairs. Most of the time I feel sure that the absorbing delights and quiet terrors of exploring QWERTY worlds will suffice to draw adventurous economists into the systematic study of essentially historical dynamic processes, and so will seduce them into the ways of economic history, and a better grasp of their subject.

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THE FABLE OF THE KEYS*

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I. Introduction

THE term "standard" can refer to any social convention (standards 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 economic 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]

* Earlier drafts benefited from seminars at Clemson University and North Carolina State University, and we would like to thank the participants at those seminars. We would also like to thank James Buchanan, Dan Klein, Bill Landes, Nancy Margolis, Craig Newmark, John Palmer, Gregory Rehmke, George Stigler, and Wally Thurman for their suggestions.

[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

[*Journal of Law & Economics*, vol. XXXIII (April 1990)]

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 sometimes 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

difficult in the case of standards. The current literature fails to explain why these "externalities" are particularly relevant for standards. We will have more to say about this in forthcoming work.

[2] See, for example, Joseph Farrell & Garth Saloner, Standardization, Compatibility, and Innovation, 16 Rand J. Econ. 70 (1985); Michael L. Katz & Carl C. Shapiro, Network Externalities, Competition, and Compatibility, 75 Am. Econ. Rev. 424 (1985); and Jean Tirole, The Theory of Industrial Organization (1988).

[3] "Qwerty" stands for arrangement of letters in the upper lefthand portion of the keyboard below the numbers. This keyboard is also known as the Sholes, or Universal, keyboard.

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

[5] Paul A. David, Clio and the Economics of QWERTY, 75 Am. Econ. Rev. 332 (1985); and Paul A. David, Understanding the Economics of QWERTY: The Necessity of History, in Economic History and the Modern Economist (William N. Parker ed. 1986).

market-failure fables. It is an example of market failure that will not withstand rigorous examination of the historical record.[6]

II. 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 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 a recent article on standards, Joseph Farrell and Garth Saloner[7] present a formal exploration of the difficulties associated with changing from one standard to another. They construct 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 coin 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. 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 differentiated from the far more common invention of new standards 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 their choice of that standard, but their continued use of the old standard is not inefficient; would it not be foolish to lay all regrets at the doorstep of externalities?

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 partici-

[6] See Ronald H. Coase, The Lighthouse in Economics, 17 J. Law & Econ. 357 (1974); and Steven N. Cheung, The Fable of the Bees: An Economic Investigation, 16 J. Law & Econ. 11 (1973). Our debt is obvious.

[7] Farrell & Saloner, *supra* note 2.

pants can communicate perfectly. 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 Coase offered decades ago.[8]

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 internalizing the externality and 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 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.[9] 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

[8] Ronald H. Coase, The Problem of Social Cost, 3 J. Law & Econ. 1 (1960). Of course, 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. Recall the well-known discussion of Harold Demsetz, Information and Efficiency: Another Viewpoint, 12 J. Law & Econ. 1 (1969), on the nature of efficiency. If a 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] 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.

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.[10]

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 fee.[11]

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 indistguishable from pure chance.

Consideration of the many complicating factors present in the market

[10] David, Understanding, *supra* 5. Additionally, see Herkimer County Historical Society, The Story of the Typewriter: 1873–1923 (1923), which notes that in the early 1920s a single typewriter company was placing 100,000 typists a year.

[11] Arthur Foulke, Mr. Typewriter: A Biography of Christopher Latham Sholes 106 (1961), which notes: "Present old 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."

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 emprical verification can determine if these abstract models have anything to do with reality.

III. The Case for the Superiority of the Dvorak Keyboard

Paul David[12] introduces economists to the conventional story of the development and persistence of the current standard keyboard, 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 were approaching 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 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 the first 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

[12] David, Clio and the Economics of QWERTY, *supra* note 5.

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 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, however, imply 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.

IV. The Myth of Dvorak

Farrell and Saloner mention the typewriter keyboard as a clear example of market failure.[15] So, too, does the textbook by Tirole.[16] Both

[13] This history follows David, Clio and the Economics of QWERTY, *supra* note 5, but also see Wilfred A. Beeching, A Century of the Typewriter (1974), as an example of an account with the features and emphasis described here.

[14] David, Clio, *supra* note 5, 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 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 2,200 percent?

[15] Farrell & Saloner, *supra* note 2.

[16] Tirole, *supra* note 2, at 405, states: "Many observers believe that the Dvorak keyboard is superior to this [Qwerty] standard, even when retraining costs are taken into account.

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 claim that Dvorak is a better keyboard is supported only by evidence that 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.

A. *Gaps in the Evidence for Dvorak*

Like most of the historians of the typewriter,[17] 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?"[18]

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. Several theorists use 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.

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 (federal, state, and local governments, Fortune 500 companies, etc., often have tens of thousands of employees, and these organizations could undertake the training if the costs really are compensated in a short time. See notes 11 and 14 *supra*.

[17] For example, see Beeching, *supra* note 13, or Foulke, *supra* note 11.

[18] David, Understanding, *supra* note 5, at 34.

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 coauthors in 1936 included some of Dvorak's own scientific inquiry.[19] Dvorak and his coauthors compared the typing speed achieved in four different and completely separate experiments, conducted by various researchers for various purposes.[20] One of these experiments examined the typing speed on the Dvorak keyboard, and three 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 that 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 coauthors seems particularly open to question. Their book is more in the vein of an inspirational tract than a scientific work. Consider the following (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.[21]

[19] August Dvorak, Nellie L. Merrick, William L. Dealy, & Gertrude C. Ford, Typewriting Behavior (1936).

[20] *Id.* at 226.

[21] *Id.* at 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?[22]

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."[23] 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.[24] The report does not state who conducted the study. It consists of two parts, the first based on an experiment conducted in July 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 chosen, but it does not appear to be based on a random process. At least twelve of these individ-

[22] *Id.* at 217.

[23] Foulke, *supra* note 11, at 103.

[24] 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, and 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, D.C. (July and October 1944).

uals 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 dexerity 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 had net scores of zero words per minute initially, 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.[25]

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.

[25] It is not an innocuous change. We are told 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 (at 20). 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 wish to 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. 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. The effect of the truncation at the end of the measuring period cannot be determined with any accuracy, but there is no testing effect to be removed at this stage of the experiment after many tests have been taken. While the apparent effect of these measurement techniques is significant, the indisputable problem is that they were not applied equally to the Qwerty and Dvorak typists.

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 underperforminig 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: "Indisputably, it is obvious that the Simplified Keyboard is easier to master than the Standard Keyboard."[26] Later they 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."[27]

There are other problems of credibility with these Navy studies having to do with potential conflicts of interest. Foulke[28] 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 Amercian Standards Association, reports that the 1944 Navy experiment and some Treasury department experiments performed in 1946 were conducted by Dr. Dvorak.[29] We also

[26] Navy, *supra* note 24, at 2.

[27] *Id.* at 23.

[28] *Supra* note 11, at 103.

[29] Earle P. Strong, A Comparative Experiment in Simplified Keyboard Retraining and Standard Keyboard Supplementary Training (U.S. General Services Administration 1956). However, Yamada, trying to refute criticisms of Dvorak's keyboard, claims that Dvorak did not conduct these studies, he only provided the typewriters. See Hisao Yamada, A Historical Study of Typewriters and Typing Methods: From the Position of Planning Japanese Parallels, 2. J. Information Processing 175 (1980). He 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.

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.[30]

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.[31] This study is ignored in David's history for economists and is similarly ignored in other histories directed at general audiences. Strong conducted 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 for these typists to catch up to their old Qwerty speed. (Compare this to the claim David makes about the Navy study's results that the full retraining costs were recovered in ten days.) When the typists had finally caught up to their old speed, Strong began the second phase of the experiment. The newly trained Dvorak 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 those firms and government agencies responsible for choosing typewriters.[32]

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

[30] Yamada, *supra* note 29.

[31] Strong, *supra* note 29.

[32] 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 U.S. Plans to Test New Typewriter, New York Times, November 11, 1955; Revolution in the Office, New York Times, November 30, 1955; Key Changes Debated, New York Times, June 18, 1956; U.S. Balks at Teaching Old Typists New Keys, New York Times, July 2, 1956; and Peter White, Pyfgcrl vs. Qwertyuiop, New York Times, January 22, 1956, at 18.

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.[33]

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 is that all firms would change to a new standard if only they 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 degree(s); 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 experiment[s] . . . may indicate that the true reason of their criticism lies elsewhere.[34]

This is one nasty disagreement.[35]

Nevertheless, Yamada as much as admits that experimental findings

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

[34] Yamada, *supra* note 29, at 189.

[35] Also see note 29 *supra*.

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 better.[36] 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.[37] 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.[38] 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.[39] 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.

B. *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 advantages of the Dvorak 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."[40] In two studies based on analysis of hand-and-finger motions, R. F. Nickells, Jr., finds that Dvorak is 6.2

[36] Yamada, *supra* note 29, at 185.

[37] *Id.* at 188.

[38] *Id.*

[39] 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.

[40] A. Miller & J. C. Thomas, Behavioral Issues in the Use of Interactive Systems, 9 Int. J. of Man-Machine Stud. 509 (1977).

percent faster than Qwerty,[41] and R. Kinkhead finds only a 2.3 percent advantage for Dvorak.[42] Simulation studies by Donald Norman and David Rumelhart find similar results:

> 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.[43]

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.[44]

[41] Cited in Hisao Yamada, Certain Problems Associated with the Design of Input Keyboards for Japanese Writing, in Cognitive Aspects of Skilled Typewriting 336 (William E. Cooper ed. 1983).

[42] Cited in *id.* at 365.

[43] Donald A. Norman and David E. Rumelhart, Studies of Typing from the LNR Research Group, in Cognitive Aspects of Skilled Typewriting 45, 51 (William E. Cooper ed. 1983).

[44] *Id.*

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.

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 that David cites. 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.[45]

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.

C. *Typewriter Competition*

The Sholes typewriter was not invented from whole cloth. Yamada reports that there were fifty-one inventors of prior typewriters, including

[45] George C. Mares, The History of the Typewriter (1909).

some earlier commercially produced typewriters. He states: "Examination of these material(s) reveal that almost all ideas incorporated into Sholes' machines, if not all, were at one time or another already used by his predecessors."[46]

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,[47] the machines were close rivals, and they each sold in large numbers. 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.[48] 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.[49] 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.[50] This firm was the forerunner of the Smith-Corona company.

Two manufacturers offered their own versions of an ideal keyboard: Hammond in 1893 and Blickensderfer in 1889.[51] 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 ap-

[46] Yamada, *supra* note 41, at 177.

[47] *Id.* at 181.

[48] Beeching, *supra* note 13, at 165.

[49] *Id.* at 214.

[50] *Id.* at 165.

[51] David, Understanding, *supra* note 5, at 38. Also see Beeching, *supra* note 13, at 40, 199. Yamada, *supra* note 29, 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.

peared 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.[52] 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 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.[53] 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 nonstandard. 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

[52] Herkimer County Historical Society, *supra* note 10, at 78.

[53] 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 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.

or the chance association of this keyboard arrangement with the only mechanically adequate typewriter.

D. *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 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."[54]

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*[55] reported on a typing demonstration given the previous day in Brooklyn by a Mr. Thomas Osborne of Rochester, New York. The *Times* reported that Mr. Osborne "holds the championship for fast typing, having accomplished 126 words a minute at Toronto August 13 last." 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."[56] Note that this was just months after McGurrin's Cincinnati victory.

There were other contests and a good number of victories for McGurrin and Remington. On August 2, 1888, the *Times*[57] 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 the received history, according to which McGurrin is the only person to have memorized the keyboard, it is inter-

[54] Beeching, *supra* note 13, at 41.

[55] New York Times, February 28, 1889, at 8.

[56] *Id.*

[57] *Id.* at 2.

esting 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*[58] 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.

V. Conclusions

The trap constituted by an obsolete standard may be quite fragile. Because real-world situations present opportunites 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.[59]

[58] *Id.*

[59] See text at notes 30–43.

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

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. 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 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

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.

paths. A model may assume that consumers have foresight or even that they are perfectly rational, but always 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 telling, "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 it is bad relative to any other observers.

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 interpreations that result are not graced with the truth that Cicero asks of historians.

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