



CAPRI

CENTER FOR THE ANALYSIS OF PROPERTY RIGHTS AND INNOVATION

How the Lock-In Movement Went off the Tracks

Stan J Liebowitz

Stephen E. Margolis

CAPRI Publication 06-03

Liebowitz is on the faculty at the School of Management, University of Texas at Dallas and Margolis is on the faculty at North Carolina State University.

How the Lock-In Movement Went off the Tracks

Stan J. Liebowitz
University of Texas at Dallas

Stephen E. Margolis
North Carolina State University

October 2010

Twenty years ago we published “The Fable of the Keys,” in which we presented evidence that the QWERTY keyboard standard did not support the proposition that markets are likely to fail in choosing standards in the presence of increasing returns to adoption. We also observed that models tended to ignore those aspects of actual markets that made them unlikely to succumb to being “locked-in” to inferior choices. In subsequent writings, we further elaborated these points, offered a taxonomy relating different types of lock-in claims to market failure, and presented rebuttals of other proffered examples of this type of market failure. This paper examines responses to our work from leading proponents of lock-in theories which have been quite remarkable for their tone and content. Those writers now argue that their market failure theories require no empirical support at all. Further, they allege that they never cared about market failure and they never meant to have their empirical evidence taken literally. They also misunderstand or misrepresent our arguments.

Introduction

Twenty years ago we published “The Fable of the Keys” in the *Journal of Law and Economics* (1990). That paper addressed a then-new and active literature in economics that put forward a new category of market failure. Papers by Michael Katz and Carl Shapiro (1985), Joseph Farrell and Garth Saloner (1985), Paul David (1985), and Brian Arthur (1989) all identified related forms of inefficiency that arise in the presence of particular forms of increasing returns to scale. For Katz and Shapiro, these effects were *network externalities*. Their treatment followed from a common observation about actual networks, which is that the benefit to each participant in a network increases with the size of the network. Generalized, this term was applied to a variety of circumstances in which the benefits of owning a product, or using a standard, or, in fact, taking any action, increased with the number of people doing the same thing. The term network externality captured the tenor of much of this literature, reflecting a view that these interaction effects are not internalized. Given that view, much of the literature held that where these effects are present, markets would, likely as not, make mistakes. Unlike more traditional externalities, however, the markets wouldn’t just choose the wrong amount of a product, but would actually choose the wrong products, the wrong networks, or the wrong technologies; a new type of market failure.¹

Papers by Brian Arthur and Paul David are prominent in this literature. Each of them uses the terms *path dependence* and *lock-in* to describe an implication of increasing returns models. In their analyses, network effects imply that a head start could easily be decisive in determining which one of several competing products or technologies would survive in the marketplace. Thus a head start, and not merit, could determine outcomes. A head start could be due to most anything—a personal quirk, an accident, some fleeting advantage.

Arthur and David drew on a handful of examples of allegedly bad outcomes, apparently with the intent of providing empirical support for their theoretical claims: Gasoline prevailed over electricity and steam for automobile propulsion, VHS prevailed over Beta for video recording, and, most prominently, the QWERTY keyboard prevailed over Dvorak. In “Clio and the Economics of QWERTY,” in the May 1985 issue of the *American Economic Review*, Paul David retold an old story that holds that the first commercially successful typewriter established a keyboard arrangement, QWERTY, which was expedient given the technology of the day, achieved dominance through a lucky stroke of being associated with the world’s first touch typist, but was substantially inferior to other keyboards, particularly the Dvorak keyboard, which arrived seventy years later. Sadly, in David’s telling, we have been unable to switch to this better keyboard. We don’t switch to the Dvorak keyboard because Dvorak keyboards are hard to find, and Dvorak keyboards are hard to find because few people have switched to Dvorak. We are “locked in.”

¹ We argued that these effects can be internalized and have urged the use of the phrase *network effects* for the general case and that terminology appears to have been generally adopted. See our 1994 paper.

David's paper became one of the most cited papers in economics.² Economists who offered theoretical models of network externality and lock-in cited David for empirical support. Just as everyone writing on the subject of network effects needed to cite the Katz and Shapiro paper, they also needed to cite a real-world example. David's typewriter story was it.

This new type of market failure, which results in the wrong activity, in contrast with the more conventional failure which results in the wrong amount of the activity, attracted a great deal of attention in economics and other social sciences. It has also influenced public policy. Eventually lock-in came to play a central role in the arguments that brought Microsoft into the focus of the Justice Department's Antitrust Division.³ The European Commission's antitrust unit has also embraced lock-in stories.

We were skeptical about these claims. We were puzzled why, given Dvorak's superiority, there was no real shift to Dvorak in a world of personal computing where keyboards could be rearranged almost costlessly. This led us to look into the details of Dvorak's superiority. We found that Dvorak's superiority was a myth; a myth that taught a lesson, a fable. Our inquiry led us to a great deal of evidence that Dvorak offered no real advantage. We published these findings in "The Fable"

Beginning with "The Fable," we have challenged several other examples of market failure put forward by Paul David, Brian Arthur, and others. It has never been our claim that such failures are impossible, but rather that they are apt to be rare, owing to the likelihood that market adaptations can alleviate such traps. These market adaptations include things like participant foresight, advertising, leasing, adoption by large firms or, more generally, entrepreneurial actions. By their nature, these adaptations are not guaranteed to save the day, but neither can they be ignored. To date, these writers have failed to provide examples that can withstand scrutiny in which feasible superior alternatives fail in the marketplace.⁴

We also became skeptical about the foundations of lock-in theories. In subsequent writings (1994, 1995a, 1995b, 1996, 1999) we have tried to make economic sense of the general terms "lock-in" and "path dependence." In doing so, we have engaged in a debate with Paul David, Brian Arthur and others on related conceptual and empirical issues. The rest of this paper recounts some of this debate and comments further on it.

² Although the 1985 paper by Katz and Shapiro that largely started this literature receives (as of April 2010) 3763 cites in Google Scholar, the two papers making explicit claims for lock-in inefficiency and seeming to provide examples supporting these claims are equally well cited: the 1985 keyboard paper by Paul David gets 3681 and the lock-in paper by Brian Arthur (1989) gets 3772 cites. Although the absolute number of citations are lower using ISI data, the conclusion is the same.

³ See the brief by Gary Reback which liberally sprinkled terms such as "lock-in" throughout and for which Brian Arthur and Garth Saloner served as advisors.

⁴ Note that it has never been our claim that the choice of some non-market standards, such as languages, political choices, legal systems, and so forth, are necessarily or even mainly efficient. We have explicitly limited our analysis to market based examples since it is those cases that offer entrepreneurs profit-making opportunities from overcoming incumbents, and it is the desire for profits that motivates actions to overcome lock-in.

David's criticisms of our work have been numerous and shrill. For the most part, we have declined to respond to his criticisms, or Brian Arthur's, instead letting our work speak for itself since we believed their criticisms to be clearly invalid.⁵ But now, twenty years after the publication of our first article on these topics, it seems time to reflect on this debate, to consider the merits of various rejoinders to our work and to consider how these theories have fared over these two decades.

1. Our "Fable," and Their Responses

"The Fable of the Keys," was in large part a response to Paul David's paper, "Clio and the Economics of QWERTY." There were other motivations, of course. The theoretical paper by Katz and Shapiro along with a paper by Farrell and Saloner, which we cited in the opening paragraphs of "The Fable," were important, as was Brian Arthur's work. At the time, the keyboard example was being widely used in support of theoretical models of network effects or increasing returns more generally. Modelers working on this subject referenced David's presentation of the keyboard story as support for their theoretical results that markets might select the wrong products or standards.⁶

The QWERTY-Dvorak story, including the view that standardization on QWERTY is an unfortunate system-wide outcome, was widely if not commonly known prior to David's 1985 paper. It was David, however, who put the story squarely in front of economists and associated the tale with theories of path dependence and lock-in that Brian Arthur and was promoting at the time. In "The Fable," we showed that David's presentation of the history of the keyboard was incorrect in various ways: A study attributed to the U.S. Navy, which was an important basis for David's claim of Dvorak's superiority, was of dubious quality and appears to have been conducted by Dr. Dvorak.⁷ There were also studies, most importantly a well publicized study by the US General Services Administration, overlooked by David, that found little or no advantage for the Dvorak keyboard. We also found that in typing speed competitions in the 1880s, there were touch typists using and winning with competing (non-QWERTY) keyboard designs. That finding is important because it contradicts one of David's central claims, which is that QWERTY came to be regarded as the best keyboard format because the world's only competitive touch typist just by happenstance used a QWERTY typewriter.

Further, we noted that David failed to consider real-world circumstances that could unravel the QWERTY trap if Dvorak really were significantly better. For example, large firms switching to the Dvorak format could internalize a substantial portion of would-be external effects and, if David's claims about Dvorak's superiority were true, should have been able to earn extraordinary returns. We also found that QWERTY had competed and won in market competition with rival typewriters that offered alternative keyboard formats. In "The Fable," we also introduced arguments, which we would develop more

⁵ We assumed, incorrectly, that David's shrill responses would have little impact on the discussion. Based on Google Scholar numbers, we were wrong. David's various responses have generated upward of 600 citations.

⁶ For a wider set of possible examples, see Arthur 1990.

⁷ Also, as we suspected, Gomes (1998) reported that David admitted to not having read the Navy study.

fully in later writings, that QWERTY-like traps are likely to be fragile in the face of forward-looking decision makers and profit seeking entrepreneurs.

David's defenses of his work have arrived over the years, particularly in four similarly themed papers (1997, 1999, 2000, and 2007) that are quite lengthy, though with considerable overlap.⁸ In these writings, David has sought mostly to reposition his argument. While he had promised to respond to our criticisms of his telling of the keyboard story, he has failed to do so and now he says there is no point in doing so. Another of David's responses is a surprising claim that market failure was never an important part of his QWERTY argument. A further remarkable claim, one that Brian Arthur also makes, is that there is no need for empirical inquiry into the importance of path dependence, because the theory alone is quite enough. We take up each of these in turn.

a. David's QWERTY No-Show

In all of his many writings related to path dependence, David has never directly addressed our account of the history of the typewriter keyboard. He has suggested that he would, but hasn't followed through.⁹ For example, as late as 1997, he stated:

It is proper for me at the outset to caution those readers who are hopeful of finding herein some further technical details and narrative material on the evolution of typewriter keyboard layouts. Although they are going to be disappointed on that account, there will be another, more suitable place in which to consider my detailed rejoinders to the dubious factual allegations that have circulated concerning the 'true story' of QWERTY.*

[His footnote to this reads,] * I refer in this regard to Liebowitz and Margolis's (1990) dismissal of the version of the story of QWERTY presented by David (1985, 1986) as "a specious example of market failure borne in part from insufficiently rigorous examination of the historical record"...The historical arguments and evidence offered to support that critique are re-examined in my forthcoming paper: 'Neoclassical economists and the keyboard: Is there a cure for repetitive thought injuries?' (1997, p. 7)

⁸ Two of these papers appear to share portions of their titles and thus might be different versions of a single paper, but since each appears to contain novel material we cite them as separate papers. These papers, in chronological order can be found, at:

<http://web.archive.org/web/20060111113709/http://www.nuff.ox.ac.uk/economics/history/paper20/david3.pdf>;

<http://emlab.berkeley.edu/~bhall/qsremedy.pdf> ;

<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.8.1.129&rep=rep1&type=pdf> ;

<http://www.master-ape.ens.fr/wdocument/master/cours/histo1/David%20Path%20Dependence.pdf>

⁹ The mention of a "forthcoming paper" in the attendant quote may well have been meant as a joke. His references did not include this paper, it was never published, nor, as far as we can tell, has it been posted as a working paper. Still, his mention of "another, more suitable place in which to consider my detailed rejoinders to the dubious factual allegations" may suggest some intention to provide a reply.

Although thirteen years have passed since he made these statements, David's rebuttal has not appeared. Further, it seems that David had publicly given up on that particular quest merely two years later:

As this was not a direction in which I felt it would be particularly useful to encourage others to invest their time, it seemed best to decline invitations to become engaged in debates with the die-hard skeptics whose attacks on the concept of path dependence were formulated as disputations of the historical evidence regarding the story of QWERTY...Indeed, focusing so much attention on the efficiency aspect of this particular case, as if the relevance for economics of the whole subject of multiple equilibria in stochastic processes (and the mechanisms whereby "selection" occurs among them) somehow turned upon the answer to it, strikes me as wrong-headed. [1999, p. 9]

David apparently has given up on the possibility of finding a "more suitable place" in which to address our "dubious factual allegations." We leave it to the reader to decide why his rebuttal has not been forthcoming.

Although David has not pursued the QWERTY story any further, others have. There is an extended discussion of these matters at the Economic History Research Website. Our reading of these discussions is that the QWERTY story is no longer widely viewed as a correct example of path dependent market failure.¹⁰

One compact and apparently influential contribution to EHR discussion comes from Deirdre McCloskey:

I am looking out at the Sears Tower in Chicago. The company must employ--what?--5,000 typists in that building alone. They now work on computers, not Remingtons. The hardware change to a new keyboard is trivial. The retraining cost of the workers is small--what, a week? Two? For a big gain, allegedly, in typing speed. Why hasn't Sears done it? Or any company anywhere the world? We're talking not of a centralized, political decision like nuclear power...but thousands upon thousands of opportunities for profit allegedly spurned.¹¹

In "The Fable," we noted that the alleged superiority of the Dvorak keyboard implied that large firms were missing out on large profit opportunities. Such "spurned" forgone profit opportunities remain a decisive liability for the market-failure version of path dependence.

b. Market Failure was Never Important

Having declined to address our arguments in "The Fable," David pursued another line of defense. His principal defense is to claim that we have been barking up the wrong tree,

¹⁰ Readers can draw their own conclusions, of course. These discussions can readily be located by searching <http://www.eh.net/>

¹¹ Economic History Research 2005-11-16 20:03 <http://eh.net/content/ehr-path-dependency-17> (Some emphasis and parenthetical comments removed. They were out of place here.)

that market failure was never important to his writing or thinking, that it was always just a side issue.

Most prominent among the misapprehensions that have emerged in the literature during the past decade, at least to my way of thinking, is the notion that the condition of “path dependence” somehow is responsible for “market failures” which, in turn, result in persisting irremediable inefficiencies in the allocation of resources. [1997, p. 8]

After noting that “so many economists continue to be hung up on the question of whether or not QWERTY is the best keyboard available today,” David concludes,

For scholars seriously interested in the historical development of typewriting technology this could be a reasonable obsession. But, to suppose that it is substantively crucial to any of the interesting issues [that] surround path dependence and its economic policy implications is just plain silly. [1999, p.9]¹²

Apparently it is “just plain silly” to suppose that economists should look for some empirical grounding of a theory before we begin to consider its “policy implications.”

Elsewhere, David offers, in an unserious way, to accept some “blame” for using the QWERTY example, and for allowing it to become “the now popular emblem of path dependence,” providing he can “enter a plea of ‘mitigating historical circumstances.’” His excuse is that he had accepted an invitation to speak at the 1984 AEA meetings, charged with giving a talk that would encourage economists to pay more attention to economic history:

What message, compressed into so brief a time span, would persuade the economist in the street to turn his or her mind to the possibility that history might matter in what they were doing professionally? Getting the attention was a first requirement, and so my talk would begin with references to sex. Seizing the audience’s attention was one thing, but how to keep it? One generally reliable tactic of reinforcement suggested itself: the application of a stimulating shock. What is the subject that holds economists even more than the mention of Sex? Inefficiency! (1997 p. 9).

Thus, he acknowledges that he incorporated claims of inefficiency in his 1985 paper and that he expected this claim to animate economists.¹³ But it was just a rhetorical trick, he tells us, and he didn’t really mean it. It was all in the good cause of gulling the unwashed “economist in the street,” afflicted with a short attention span, into appreciating economic history. Economic inefficiency was just an unimportant by-product.

We might take him at his word that he meant to say only that history is important and that it was but an accident that he talked about market failures at all. But the evidence is to the contrary. It is easy to find examples in David’s writing where he makes the same market failure claims but where there is no available excuse that he was trying to hold the

¹² The version of the paper we have is not paginated, so page numbering is ours.

¹³ The full version of that paper, replete with the cited references to sex, appears in David (1986). Our citations on this page, however refer to David (1985).

interest of bored economists sitting in a hotel conference room. For example, in a 1988 paper with Bunn, written before he became aware of our work, he states:

Under unregulated competitive conditions, significant increasing returns to scale - or analogous positive feedback mechanisms such as 'learning by doing' and 'by using' - can cause one particular formulation of a network technology (VHS-formatted VCRs, or QWERTY formatted keyboards) to drive out other variants and so emerge as the de facto standard for the industry. By no means need the commercial victor in this kind of systems rivalry be more efficient than the available alternatives....This is a disquieting message for those who normally find comfort in the Panglossian presumption that 'the invisible hand' of market competition, assisted sometimes by the visible hand of farsighted management, somehow has worked to shape ours into the most economically efficient of all possible worlds. Yet, the presence of network externalities should predispose one to be extremely skeptical about the validity of that proposition...

Another important, if rather less contentious, message...

So the inefficiency implication was, in his words "important" and "contentious". Or it was until someone pushed back on his empirical examples. When his empirical claims are questioned, David's response devolves into a claim that it was just a one-time prop used to rouse an otherwise bored convention audience although his published statements subsequent to his 1985 article contradict that claim.

Later, in a paper with Greenstein (1990) he is still highlighting inefficiency:

In self-reinforcing processes (i.e., dynamical systems characterized by increasing returns, learning, and other sources of positive feedback) social optimality is problematic... low probability events can reinforce a course of action (through subsequent, conditional choices) that issues ultimately in a regrettable outcome - one that leaves the decision-maker(s) worse off than they would have been had the realization of the stochastic process conformed more closely to expectations... In stochastic systems with the same properties, the social efficiency of the sequence (or "path") is not assured either... [p. 11]

In that paper, he talks about ex ante and ex post inferior standards and spends several pages on whether chosen standards are efficient or not.

Nor is his attention to inefficiency (before he swore he was never interested in it) surprising. Regardless of David's claimed intentions, his focus on efficiency is demonstrably the main reason that his QWERTY paper is among the most cited papers in economics.¹⁴ A majority of the articles citing David's 1985 article cite it for its claim that path dependence can lead to inefficient outcomes, a la QWERTY. Without this claim, his

¹⁴ We examined citations from the 2008 ISI and discovered that 61% of the articles citing David's 1985 paper did so in reference to economic inefficiency. Further, 36% of the articles mentioned the typewriter keyboard specifically, indicating the importance of the factual keyboard story.

1985 article likely would not be one of the handful of the most frequently cited articles in economics.¹⁵

David must have been well aware that his claims of inefficiency were important to his audiences—not just the bored convention attendees, but more generally among academic readers. Why else would he trot out alleged examples of inefficiency and put them at the center of his articles?

c. The Burden of Proof

Probably the most surprising response to our investigation of QWERTY (and our examinations of other examples) was how it changed David's and Arthur's positions regarding the importance of empirical demonstration of the validity of their market failure claims.

David's "Clio" was, at the most basic level, an empirical paper that appeared to provide support for the theories of path dependence (for which David cites Arthur), and for the theories of network externality (for which David cites Katz and Shapiro). At the same time, Arthur, David, their students and others, were looking for empirical support in standards or technologies such as video recorders, railroad gauges, nuclear reactors, automobile propulsion, quadraphonic audio and particularly QWERTY.¹⁶ But after the QWERTY story was discredited, David and Arthur took the unusual position that neither they nor anyone else need conduct any empirical examination of the theory of inefficient lock-in associated with path dependence.¹⁷

In David's words:

[I]t is difficult to see any justification for accepting the burden of proving empirically that the outcome of a competitive market process has been other than efficient, given that you have established empirically that the case under examination is one in which the source of the positive feedback in the system is the presence of positive (network) externalities, or non-convexities such as learning effects and habituation... So, then, the burden of proof plainly falls on those who say that everything has turned out for the best; that QWERTY is better—in terms of social efficiency criteria -- than anything that was and is available. [p 9, 1999]

And here is Brian Arthur in an interview:¹⁸

¹⁵ The 1985 Clio paper is the third most frequently cited paper published in the American Economic Review since 1985 according to Google Scholar, using Harzing's 'Publish or Perish' program at three year intervals to find the most highly cited papers in the journal. If the 61% of the citations that relate to efficiency were removed (see footnote 14), the article, although still highly cited, would no longer be among the very top, dropping to number 34.

¹⁶ Puffert (2000) on railway gauges, Cowan (1990) on Nuclear Reactors, Kirsch (1996) on electric cars, Postrel (1990) on quadraphonic sound. These were all Stanford doctoral dissertations written in the late 1980s and early 1990s.

¹⁷ This is discussed in Peter Lewin (2002)

¹⁸ The text of the 1998 interview from Pretext Magazine, from which this is taken can be found here: <http://web.archive.org/web/20001025153550/http://www.pretext.com/may98/columns/intview.htm>

I find I'm puzzled by all of this because it's a bit like debating evolution with creationists...The onus isn't on me or anyone else, to show that we're locked in to any inferior thing. The onus is on the opinion page of the Wall Street Journal and the libertarians to show that all things that we're using in the economy are not just the best they could have been at the time, but are the best that could possibly have emerged...As for the QWERTY keyboard, if Margolis and Liebowitz can prove it's the best, my hat is off to them.

Of course, it has never been our argument that all markets are always perfectly efficient. The suggestion that we claim such perfection is one of several straw men that David (and here Arthur) creates. Our position, as is readily apparent in our writings, is merely that for a market to be locked-in to something that is widely understood to be inferior requires more than just increasing returns or network effects, but in addition that an array of potentially profitable internalizing activities fail. These extra conditions imply that the kinds of failures that David and Arthur predict, though possible, are likely to be uncommon or of little economic importance. Further, we would be open to the possibility that our analysis is wrong—perhaps many markets fail under these conditions of positive feedback—if there were sufficient empirical evidence.

In contrast, for David and Arthur, the theory as they present it is now its own proof. Although they (e.g., Arthur 1990) were happy to present empirical claims regarding the keyboard, or internal combustion engines, or VHS video recorders, back when no one else was looking carefully, after being challenged they now argue that such empirical claims are irrelevant. In effect, they now assert that there is no possibility that the theory they present could be incomplete in ways that matter for any of the questions at hand.

One might argue, seemingly in David's defense, that his path-dependence-as-market-failure claim should be accorded the same status as the related concept of externality. Externality certainly has acceptance among economists. Economists do, of course, debate specific externality claims, but the core idea is taken to have empirical validity. Witness its compulsory if desultory treatment in most introductory and intermediate microeconomics textbooks. An externality is said to exist if an action by A affects the well-being of B, but A does not take that effect into account. One might be tempted to add, echoing David, that once you have established the condition that A affects B, "the burden of proof plainly falls on those who say everything has turned out for the best."

The problem with this argument is that empirical examination is an essential part of the externality literature. First, there is a broad set of examples in which the simple condition that "A harms B" is fully internalized by private actions. Work-a-day examples include things like shopping centers or large-scale land developments such as golf courses that include surrounding home sites as means of internalizing common commercial or amenity externalities. There is the whole world of community and professional norms that exist to ameliorate external effects. Consequently, a claim of externality on the mere observation that A affects B is typically not accepted at face value, but is ordinarily subject to further scrutiny.

Second, and more fundamentally, the theory of externality has substantial empirical content. It is doubtful that externality theory would be a part of the economic cannon if

there were no compelling examples of actual externality and instances in which collective action is regarded as a cost-effective response. So far, the same cannot be said for strong forms of path dependence and lock-in.

There are, of course, alleged examples of externality that turn out, on closer inspection, to have been incorrect. There have also been conceptual errors pertaining to externality. In particular, the mere observation of an interaction or the presence of some harm does not establish a welfare relevant externality. Much of Coase (1960) is about exposing logical and empirical errors in claims and policy recommendations regarding externality. Surely, whether one is arguing for or against a claim that any particular externality exists, some empirical inquiry is essential. We would not have thought that this methodological view was controversial.

It is also important to keep the terms of the debate consistent. Arthur muddies the water by switching the analysis, from failures in markets, which have been the sole focus of our analysis, to failures in non-market circumstances, where all bets on efficiency are off. When Arthur is asked by the interviewer:

But isn't an important part of your contribution your pointing out that things that get locked in aren't necessarily the best?

He replies:

This notion that the market is always wonderful and perfect is a right-wing ideological idea. People don't expect that all the friends they have are the most optimal friends. People get married; sometimes it's wonderful and sometimes it isn't. Lock-ins occur; sometimes for the best, sometimes not.

By changing the subject to failures outside of markets, Arthur makes his case an inappropriately easy one. The discussion had been about the efficiency of markets in the face of network externality or path dependence, not about the efficiency of non-market institutions. It is only the former that provide profit incentives for overcoming inefficiencies. Our arguments have always been about markets.

Putting aside ad hominem and inconsistent argumentation, there are good reasons for economists expect some demonstration that a theory of harmful lock-in has some empirical content. Most economists do accept the proposition that markets are, by and large, effective means of allocating resources. We have theoretical results that markets are efficient, admittedly under idealized circumstances. We also have substantial experience that supports the proposition. Much of that is the observation of the differences in performance between economies that rely primarily on markets and those that rely primarily on planning. Against that background, it is reasonable to ask for some illustrative example that turns out to have more than "heuristic" validity. It is reasonable to ask for stories of path dependant market failure that are true

In section 4 below, we consider several recent empirical inquiries into lock-in. Each of these cases exhibit some form of positive feedback that should lead to lock-in, according to path dependence theory. These are the cases for which the burden should shift to skeptics like us, according to David and Arthur. That is, there should be a presumption of harmful lock-in. Yet, as we will see below, in each of these cases, there is no harmful lock-in to be found.

2. Lock-In and Path Dependence: Definitions and Models

So far, we have focused on the keyboard debate and some closely related rhetorical issues. But path dependence is a more general theoretical claim that raises conceptual issues that we now examine. We start with our taxonomy of path dependence and the critical responses to it. Following that, we consider Paul David's efforts to switch his position. Finally, we consider the meaning of efficiency, particularly as it relates to policy implications.

a. A Taxonomy of Regrets and Path Dependence

Our discussions of path dependence have focused on decision makers and the information and options that are available to them at the time that they make decisions having durable consequences. That focus is the basis of the taxonomy that we offered in our 1995a paper. The organizing principle of our taxonomy is that persistence in economic decisions need not result in any meaningful inefficiency. The taxonomy leaves open the possibility of socially relevant market failures involving durable commitments, but it also deals specifically with cases where actions yield permanent consequences, but no meaningful inefficiency.

Our taxonomy presents three “degrees” or types of path dependence.¹⁹ In *first-degree path dependence*, actors make durable commitments to particular outcomes that turn out to be just right. They make a choice and that choice turns out to be the best thing to have done. There is persistence in first-degree path dependence, but no regret, no mistake, and certainly no inefficiency. Here there is no spilled milk.

Alternatively, actors can make durable commitments that are wise given all the information available at the time they made their commitments, but unanticipated events can yield payoffs such that the decision turns out to be unfortunate. This is *second-degree path dependence*. There may be regret here, but there is still no inefficiency, at least in the sense that economists use the term. There is no inefficiency because there was no way that the actors could have done any better. Given the alternatives and the information at hand, there was no better choice. The choice made is not the best one they could have made, ex post, but there is no available remedy. In second-degree path dependence there is spilled milk, but no use in crying.

Finally, there is the possibility that actors make particular durable commitments in spite of the availability of a feasible better alternative. The available alternative may have been there all along, or present at some crucial moment of choice, or it might become available later on. To say the preferred alternative is feasible means that information about the superiority of the alternative is available in time to be acted upon. We think, “I should have known better,” or even, “I knew better.” Such errors are, in principle, avoidable. This is *third-degree path dependence*. Here there is spilled milk, the spill was foreseeable and readily avoided, but nothing was done. Or, there is something still to be done to minimize the loss, yet nothing is being done. This is the only form of path dependence

¹⁹ For a more complete elaboration of this material, see our JLEO paper (1995)

that has policy relevance because only this form yields an outcome that can feasibly be improved upon.

As David presents the QWERTY story, it is an instance of third degree path dependence. According to the evidence David presents, typists could retrain on Dvorak in very little time and society would be better off if they did, even taking account of the retraining cost. The benefits of a change are much greater than the costs, yet the change is not made. As a practical and policy-relevant matter, this is an inefficiency that could, at least in principle, be remedied. The story would be a wonderful example of third degree path dependence if it were true. But as we showed in the “The Fable,” it isn’t.

David is driven to rhetorical extremes by our taxonomy of path dependence claims (e.g., David 1997 p.p. 27-29). While we take his vexation as evidence that our work is having an impact, we fear that his readers may take away a distorted view of our arguments, since David either misunderstands them or has chosen to misrepresent them.

In discussing third degree path dependence, we used terminology introduced by Oliver Williamson, who was the editor on our paper in the *Journal of Law and Economic Organization* where we first presented these ideas. Williamson (1993, p. 140) notes that a policy relevant inefficiency is one that is *remediable*. Several other writers have offered this understanding, though not this terminology. In our *JLEO* piece, we also cited closely related arguments in Coase (1964), Calabresi (1968) Demsetz (1969), and Dahlman (1979). Very simply, an outcome, however regrettable, for which there is no foreseeable possibility of doing better, is not an inefficiency in any relevant sense. Using this perspective, third-degree path dependence is an inefficiency because it involves remediable error.

The only misallocations of interest for policy purposes are those that can be remedied. In such instances, there is some reallocation of resources that would yield benefits that exceed the costs of the reallocation. Where that condition holds, there is a profit opportunity for some party that can implement the reallocation and appropriate an adequate share of the resulting surplus. Williamson and the others cited above also observe that private arrangements might emerge to remedy these potential misallocations. Where they do not emerge, it is likely because some form of transactions costs intervene. Dahlman and Demsetz, in particular, note that such transactions costs are not evaded simply by handing the problem off to the government. This does not mean that collective action can’t provide an improvement; it merely argues that it might not. Demsetz is specific: Government might help, but that can only be demonstrated by evaluation of actual policy proposals that consider all of the costs, including organizational costs, necessary to bring about some improvement.

Our objective in developing the taxonomy was to point out that although some of the alleged instances of path dependence would constitute remediable inefficiency, most would not. In both the “Fable” itself and in our *JLEO* paper, we noted that profit-seeking activity has the potential to provide solutions to the possible third degree problems that are discussed in the lock-in literature. We argued, therefore, that given the possibility of private entrepreneurial solutions to these kinds of market failures, third-degree path

dependence might be a rare occurrence.²⁰ First and second degree path dependence, as already discussed, do not involve market failure.

In light of this, it is particularly odd that David attempts to make it *our* claim that path dependence implies market failure. In a bit of rhetorical legerdemain, David refers broadly to general equilibrium results regarding efficiency in competitive markets, then states²¹ “So it follows that path dependence does not imply that competitive markets fail,” (2007, pp. 103-4). As if someone, presumably us, had ever argued that it did. David’s other writings provide more in this vein:

Given the absence of both necessity and sufficiency, it does seem to be some strange twist of intellectual history for path dependence to have been immediately identified with, much less definitionally equated to the emergence and persisting realization of states that are economically sub-optimal. But this twist in the minds of some economists is not only strangely unwarranted. It has had some seriously analytical sequelae. (1997 p. 22)

Here David is winning an argument against a phantom position that no one—not us nor anyone else as far as we know—has taken.

He continues:

In straightening out that particular tangle, I will show that path dependence is neither a necessary nor a sufficient condition for market failure (1997 p. 8).

If there is any tangle here, it is of David’s making. Note that it was David who presents the typewriter as a case in which a superior arrangement was available making it a remediable inefficiency. It was also David who states “I believe there are many more QWERTY worlds lying out there...” (1985, p.336)

Given the very well known concepts of externalities and public goods, it’s hard to imagine that anyone would claim that path dependence is a necessary condition for market failure.²² Nor have we ever argued that path dependence was a sufficient condition for market failure. Quite the opposite: Our work on this subject consistently elaborates the point that common instances of path dependence (first-degree and second-degree forms in our nomenclature) are not market failures. Of course, path dependence can yield market failure, our third-degree form, but only in uncommon instances where profitable internalizing mechanisms fail. David has simply misrepresented our work (without actually naming us in the above quotes) relating to path dependence and remediable (third degree) lock-in.

²⁰ We discuss this further in our 1990 paper (p. 22) and in greater detail in our 1995 JLEO paper, (pp. 215-17)

²¹ Specifically, David states, “Economies of scale are among those troubling sources of competitive market failure, but it has been seen that path dependence *as such* may exist in the absence of indivisibilities that give rise to economies to scale. So, it follows that path dependence does not imply that competitive markets fail.”

²² Although David does not mention us by name in these extravagant claims, the reader is certainly left to believe that he is talking about us..

From what we can tell, David is trying to swap positions; associating himself with the very reasonable position (the one that we took in opposition to his) that path dependence is unlikely to lead to market failure, and off-loading his mistakes on to us.

b. Remediability. Or is that Irremediability?

David gets himself particularly confused regarding remediability, managing to get it exactly backwards. Recall that remediable market failures are relevant because they involve some possibility of doing better, whether by private or public action. Our third-degree path dependence, the only one that involves market failure and the one with potential policy significance, involves a *remediable* market failure.

David, however, in discussing our work, writes about our “third-degree path dependence in which there is market failure leading to inefficiencies of an *irremediable* kind” (2000 p. 9). He also states (p 29, 1997): “optimally timed State action looks like the best hope for empirical justification of Liebowitz and Margolis’s (1995b, 1995c) belief that situations of inextricable, totally irremediable inefficiency are as rare as hen’s teeth.”

These statements are wrong in every way they could be. Mainly, irremediable market failures are not third degree path dependencies because they cannot, by definition, be fixed. Relevant market failures, as found in our discussion of third degree path dependence, are the ones that could be (or could have been) remediated but are (or were) not. Elsewhere, David comments that our third degree path dependence requires that remedy by either public or private orderings is not possible.²³ Here, he is wrong again.

We have no reason to believe that David would have been any less dismissive of our work if he had understood it. David refers to us, or our work, or the work of others who have taken our side, as “Panglossian,” echoing his (and Bunn’s) 1988 criticism of unnamed Panglossians.²⁴ This too is a convenient strawman. We have made a case only that markets are more robust than they are characterized to be in the abstract models that David and others have employed. This observation does not imply that improvements are

²³ See for example David 1997 pp 22-29. Among other things, David conjectures, without citation, that our third-degree path dependence “is intended to require that both private and public orderings are infeasible.” (1997 p. 29) Again, this is exactly backwards. Third degree path dependence involves market outcomes that involve remediable inefficiency, that is to say, market outcome from which there is an available improvement by any means. On this we could not have been more clear. In our JLEO paper, elaborating at footnote 3 we write, “Williamson (1993) offers the term *remediability* to describe the condition that such feasible alternatives exist and urges remediableness as the appropriate standard for public policy discussion. Similar positions have been argued by Demsetz (1969), Coase (1964), Calabresi (1968) and Dahlman (1979) among others. In the framework that these authors elaborated, market failure is not demonstrated unless a specific policy recommendation can be shown in which the benefits exceed the costs, including all the administrative costs of the policy. We note that this is not a Panglossian view of the world—the world need not be optimal—but it does alter the burden proof. Claims of market imperfections cannot be established upon the theoretical possibility of an improved allocation, but instead require demonstration that a feasible alternative exists for a particular case.”

²⁴ See for example, David (2000 p.6 and 1997 p. 10) He also labels our approach “nirvana political economy” (1997 p. 29)

never available or that collective action is never essential to bringing about those improvements. See Dixit for a similar argument regarding the Pangloss criticism.²⁵

Of course, critics may fairly take issue with our taxonomy or with our attention to remediability. But David's attacks, for all their vehemence, are simply incorrect. He seems to have misread, misunderstood, or misrepresented our work along with much of the literature upon which we draw.

c. It's About Probability Distributions, Not People, Markets, or Products.

David's other major line of defense is that in paying attention to market failure, we missed his real point, which had to do with the nature of certain types of dynamic stochastic processes (2000 p. 6). In many of David's writings on path dependence, and particularly in his later ones, he emphasizes a definition of path dependence as non-ergodic dynamic stochastic processes: "Path dependence, as I wish to use the term, refers to a dynamic property of allocative processes" (2000, p.4).

David has offered no particular model of an economy that incorporates or yields a non-ergodic dynamic stochastic process. His method is strictly reasoning by vague analogy. David has further been critical of any attempts to reduce the generality of path dependence, or to reduce it to examples, even his own. After providing definitions of path dependence (2000 p. 5) as a particular type of stochastic process, he states

The foregoing account of what the term 'path dependence' means may now be compared with the rather different ways in which it has come to be explicitly and implicitly defined in some parts of the economics literature. For the moment we may put aside all of the many instances in which the phrases 'history matters' and 'path dependence' are simply interchanged, so that some loose and general connotations are suggested without actually defining either term. Unfortunately much of the non-technical literature seems bent upon avoiding explicit definitions, resorting either to analogies or to the description of a syndrome—the set of phenomena with whose occurrences the writers associate path dependence. (2000 p. 6)

So here we see David disqualifying, at least from others, any efforts to connect path dependence to observable phenomena. David would have path dependence discussed only in the context of the most severe abstraction, an immaculate concept immune from criticism: it is a dynamic stochastic process that is non-ergodic. But then what are we left with? Critics are entitled to ask whether non-ergodic stochastic processes offer a metaphor that is at all useful. After all, there are plenty of other candidates, so why this

²⁵ Dixit incorporates Williamson's remediability test for inefficiency. He too anticipates the Pangloss criticism. "This is not a Panglossian assertion that 'everything is for the best in this, the best of all possible worlds'; the best of all possible worlds would not be beset by transactions costs. Rather it is a reminder of how much policy freedom is constrained by transactions costs. It is saying, 'This world is far from being ideal; but a would-be policy innovator would do well to think whether the existing setup is making the best of, or at least coping quite well with, the world's imperfections'" (pp. 146-47).

one? So long as we are permitted to consider only the distributional properties of these processes, and not to dig into the details of economic life that might correspond to them, we have no reason to suppose that this metaphor is particularly constructive.

But of course, David brought up the typewriter keyboard, presumably because he thought it illustrated something about path dependence and non-ergodic processes. David would like to assert the relevance of his claims to actual things, but enjoy the immunity of pure theory when his historical representations are challenged.

In other places, David does seem to be aware of a need to connect the abstraction to something real. He repeatedly invokes the analogy of “branching” to describe path dependence: “But, as has been seen, the core content of the concept of path dependence as a dynamic process refers to the idea of history as an irreversible branching process.” (2000 p. 8) Doubling down on the metaphor, he talks about identifying “critical branching points in the stream of technological and institutional evolution.” (1999 p. 7). Later we get actual “actors who are being followed until their arrival at that critical branch-point...” (2007 p. 95)

Apparently when one does try to connect the abstraction of path dependence to an actual economy, one must confront “actors” who are making decisions that are either irreversible, or reversible only at a cost. In David’s own writing, the distributional properties of stochastic processes give way to “branches,” and more literal forks in the road. That transition acknowledges that there must be some persistence of actual things behind all this—for example, objects, knowledge, institutions, organizations, durable goods. After all, there must be some reason that, as a result of some action, a position on a branch that was once obtainable no longer is. In our work, we discussed path dependence—this branching—as persistence or durability. Admittedly, this treatment does turn away from consideration of abstract stochastic processes and toward consideration of real things in the economy, things that might be the cause of those irreversibilities. But as we have shown above, even David is unable to avoid at least some of this.

In their early work on path dependence, David, Arthur, and their students were correct to look for real world occurrences of the implications of their theories. That is how science is done. Now, however, David argues that the presumption should be in favor of inefficient lock-in, giving him a reason to limit inquiry to definitions and pure mathematics.

We are not alone in suggesting that David has failed to respond in a direct manner to our criticisms. Here is Steven Durlauf (2005), a contributor to the literature of complexity and nonergodic processes, and a coeditor of a book with Brian Arthur:

The QWERTY example has been subjected to very strong attacks by Liebowitz and Margolis (1990, 1995)...David’s rebuttals to these attacks (1997, 2000) have not dealt with the specific evidence presented by Liebowitz and Margolis...his response has largely amounted to 1) arguing that Liebowitz and Margolis employ a faulty notion of path dependence...2) citing other examples of technological lock-in ...or 3) arguing that given the presence of network externalities...the burden of proof should be on Liebowitz and Margolis.

...Criticisms of the definition of path dependence as appear in the economic history literature suffer from the Socratic error of arguing that one cannot determine whether something is an instance of a class without a complete definition of the class; in this case it is certainly possible to determine whether the evolution of the typewriter keyboard standard is an instance of path dependence without addressing all aspects of the definition of path dependence...

...For this reason, suggesting that there should be a presumption in favor of findings of inefficient technological lock-in are unpersuasive... (2005, p. FF228-9)

3. Looking For Lock-in

Several researchers have looked for lock-ins to inferior alternatives in the places we might expect to find them; in markets with increasing returns. Reliably, they seem to come away empty handed.

a. Software Markets

Our own empirical work on the subject is described in greatest depth in our 1999 book.²⁶ There we examine a number of software markets to see whether any were locked-in to products that were not as good as available alternatives. Software, having both large fixed costs and, in most cases, some form of network effect, seems an ideal place to look for lock-in. We looked at numerous markets (word processors, spreadsheets, desktop publishing, home finance and so forth, on both the PC and the Mac) to see whether the products that received the highest rankings from reviewers were becoming the dominant products and whether superior new entrants could displace lower rated incumbents. The answer in virtually all cases was yes.

In a similar vein, a recent paper by Tellis, Yin and Niraj (2009) examines 19 markets (some of which were examined in Liebowitz and Margolis, 1999). They extend our analysis not only by examining new markets but also by attempting to determine whether market share has a feedback effect on quality. They conclude that the main effect runs from quality to market share, that is, better products tend to win bigger shares. They also conclude that inferior products and standards do not win out even when network effects are present. An invited discussion by several leading marketers (Ratchford et al, 2009) does indicate a variety of views, but on the whole reveals considerable doubt about the empirical relevance of lock-in.

Together, these software cases cover a large number of markets that may readily be characterized as exhibiting, in David's words, "positive feedbacks," which, he submits, should be sufficient to establish a presumption of lock-in. Yet there is no evidence of lock-in to be found in any of these cases.

²⁶ This is also discussed, although not quite as thoroughly, in our 1999a paper.

b. A Market Experiment

Taking a quite different approach, Tanjim Hossain and John Morgan (2009) test for lock-in in simulated-market experiments. In their experiments, subjects choose between two networks, each of which exhibit increasing returns. For each market simulation, there is a Pareto optimal network. In each simulation, one network is assigned higher access costs. Either network can be assigned high costs and either network can hold the initial monopoly position. In each round of the experiment, each participant selects a network. Their results, in their words: “Somehow, the market always manages to solve the QWERTY problem. In sixty iterations of dynamic platform competition, our subjects never got stuck on the inferior platform—even when it enjoyed a substantial first-mover advantage.” (p. 435)

It is easy to imagine that an experiment could be specified in which fixed costs are large enough and network effects are strong enough that some experimental design would yield lock-in. But in Hossain’s and Morgan’s experimental results, we have additional instances in which network effects are insufficient to lock-in a Pareto dominated outcome. Again, David’s presumption of lock-in on the basis of the presence of network effects would be unwarranted.

c. QWERTY in Europe: A Third Degree Claim?

Although many writers continue to cite the QWERTY keyboard as evidence of market failure, most careful analysts who have followed the literature on path dependence and lock-in have stopped calling the keyboard a market failure, at least in the sense of our third-degree type claim.²⁷ But a recent paper by Adreas Reinstaller and Werner Holzl, appearing in *Industrial and Corporate Change*, does present efficiency claims related to the universal keyboard, which is AZERTY in France and QWERTZ in Germany.

Regarding the French experience, they make a clear third degree claim: “The French case qualifies in the taxonomy of Liebowitz and Margolis (1995) as an example of third-degree path dependence, as a better alternative was available and its superiority was known at the time of adoption” (p 1020). Given the history they present, however, their claim is surprising.

For the general history they present, Reinstaller and Holzl document that both large manufacturing enterprises and commercial use of typewriters came much later to France than to the U.S. They note that in 1914, when Ford had over 200,000 employees in the U.S., Renault, had 5,000, of which only nine were typists.

Reinstaller and Holzl note that “A specific French keyboard, the ‘Clavier Francais’ was presented in 1906 in the trade journal ‘La Plume Stenographique’.” By 1908, two prominent typewriter manufacturers, Smith Premier and Underwood, offered machines that used the French keyboard. In 1909 an improved version of that keyboard was

²⁷ One of the more straightforward defenses of the Dvorak keyboard was made in a website run by Marcus Brooks, an advocate for Dvorak keyboards. He has a web page called “Fable of the Fable” where he attempts to refute some of our points. Liebowitz has posted a rejoinder to Brooks’ claims at: <http://www.utdallas.edu/~liebowit/FOF.pdf>

introduced as the “Typo”. Reinstaller and Holzl further report that the editor of *La Plume Stenographique* also organized typing competitions. (p. 1020)

Reinstaller and Holzl continue: “In 1911, the French keyboard finally experienced an upswing when a 17 year old typist trained on the ‘Typo’ at the manufacturer’s training school fared very well at typing competitions in Grenoble and Orleans.” (p. 1020) Three details caught our attention: “1911”, “trained on the ‘Typo’ at the manufacturer’s training school”, and “fared very well.”

Here we have a claim that a superior keyboard, arriving on the scene at a time that there would have been little adoption of any keyboard arrangement, and with training support, nevertheless lost out. Typo, the superior keyboard arrangement, should have won. Well, it should have won if it really were superior.

Here’s is the actual report about the typing competition mentioned by Reinstaller and Holzl:

In 1911, the French keyboard was acclaimed when a 17 year-old typist won the second prize in the French championships in Grenoble. She had been trained on the Typo by the Manufacture d’Arms et de Cycles [which made the Typo] at their School of Typing. The following year the Typo [no mention of the typist’s identity] won the first prize for practical work and second prize for speed in Orleans. (Gardy, p. 272; our parenthetical additions).

Certainly the Typo’s two second place finishes along with a first place isn’t bad (although we aren’t told how many competitors there were) but it hardly establishes superiority in any meaningful economic sense. We can’t be sure, but it seems likely that one other keyboard design, and perhaps even one other typist, had two firsts and a second. (It is possible, of course, that these results were distributed among two other typists and two other keyboard designs.) Critically, for the matter of concern in this paper, these results provide no basis for anyone to conclude that a demonstrably inferior keyboard was adopted in the face of a known superior rival.

Reinstaller and Holzl also report that in Germany, the choice of keyboard standard occurred under the watch of coordinating bodies established within the Board for Standardizations of the German Industry (Normungsausschuss der deutschen Industrie). The Board established the QWERTZ keyboard as the Standard in 1928.” (p 1018), which Reinstaller and Holzl suggest was inferior to alternatives.

Whatever the merits of the Board’s decision, this case is just the kind of collective decision making that might be held as offering a superior alternative to markets in the choice of standards. The outcome in this case is not the result of, as David has put it, “decentralized decision making” and thus offers no information about markets choosing the wrong standards.

These studies—software markets, experimental markets, and re-trials of the typewriter evolution—are significant because they all address markets that satisfy the conditions that are supposed to lead to lock-in, yet lock-in to inferior arrangements isn’t found. The accumulating evidence weighs against David’s preferred allocation of proof, cited above,

by which the mere presence of a “positive feedback” should be sufficient to defeat any presumption of market effectiveness.

4. Conclusion

When we first began writing about these topics we offered three simple claims: Lock-in was poorly defined, such that that ordinary durability could easily conflated with more exotic coordination problems; the conditions required for harmful lock-in were not fully recognized in the prevalent discussions of path dependence; and the empirical examples that were alleged to support the claim of harmful lock-in were faulty.

The response to our work arrived with some delay, perhaps with good reason--ignoring our criticism worked well for a while. When the reply did arrive, it was multipronged and peculiar: The keyboard story didn't need to be true, it's still a good story. We don't need any proof of market failure, we know it's there. Who's talking about market failure? Not us. And in case that isn't enough, we will do what we can to mischaracterize your work, you creationist Panglossians.

The principals of the path dependence movement—David and Arthur in particular—in various ways initially told their readers that they could expect to find many QWERTY stories. Scholars who claimed to find such stories might well have expected an enthusiastic reception. Yet in twenty years, there is scant evidence to support harmful path dependence as a problem, at least in market outcomes. Instead we find examples of the sort we reported above, where scholars taking a variety of approaches have searched for market failure in just the sorts of places that it should be found, but come away without finding any. Unfortunately, that hasn't stopped some authors from parroting the QWERTY lock-in story. Even more unfortunately, it hasn't stopped governments from using these discredited ideas to support misdirected antitrust policies.

Still, we would like to close on a positive note. After all, the proponents of path dependence theories have provided much fodder for us. So for those still seeking harmful lock-in, we offer this. You've been looking in the wrong places. You've been looking at markets. Look elsewhere. Look where competition is not particularly effective, where there is no possibility of bankruptcy, where there are no investors who can pull the plug on losing battles. Look where the rewards for successful innovation are unspectacular or nonexistent. Look where concentrated interests face off against unconcentrated counterparts. Look at government. Cultivate that garden.

- Arthur, W. Brian (1989), "Competing Technologies, Increasing Returns, and Lock-In by Historical Events," *Economic Journal*, 97, 642-65.
- _____ (1990), "Positive Feedbacks in the Economy," *Scientific American*, 262, 92-99.
- Calebresi, G. (1968), "Transactions Costs, Resource Allocation and Liability Rules: A Comment," *Journal of Law and Economics*, 11, 67-74.
- Coase, Ronald H. (1960), "The Problem of Social Cost," *Journal of Law and Economics*, 3, 1-44.
- _____ (1964), "The Regulated Industries: Discussion," *American Economic Review*, 54, 194-97.
- Cowan, Robin (1990) "Nuclear Power Reactors: A Study in Technological Lock-in" *The Journal of Economic History*, Vol. 50, No. 3 (September), pp. 541-567.
- Dahlman, Carl (1979), "The Problem of Externality," *Journal of Law and Economics*, 22, 141-63.
- David, Paul A. (1985), "Clio and the Economics of QWERTY," *American Economic Review*, 75, 332-37.
- _____ (1997) "Path Dependence and the Quest for Historical Economics" One More Chorus of the Ballad of QWERTY," University of Oxford Discussions Papers in Economic and Social History.
- _____ (1999), "At Last, A Remedy for Chronic QWERTY-skepticism!" Discussion Paper for the European Summer School in Industrial Dynamics.
- _____ (2000) "Path Dependence, It's Critics and the Quest for 'Historical Economics,'"
- _____ (2007) "Path Dependence: A Foundational Concept for Historical Social Science," *Cliometrica*, 1, 91-114.
- David, Paul A. and Julie Ann Bunn (1988) "The Economics Of Gateway Technologies And Network Evolution: Lessons from Electricity Supply History" *Information Economics and Policy* Volume 3, Issue 2, Pages 89-204.
- David, Paul A. and Shane Greenstein (1990) "The Economics of Compatibility Standards: An Introduction to Recent Research," *Economics of Innovation and New Technology* 1, 3-41.
- Demsetz, Harold (1969), "Information and Efficiency: Another Viewpoint," *Journal of Law and Economics*, 10, 1-22.
- Dixit, Avinash K. (1996), *The Making of Economic Policy: A Transaction-Cost Politics Perspective*, Cambridge, Mass.: MIT Press.
- Durlauf, Steven N., (2005) "Complexity and Empirical Economics," *The Economic Journal*, 115 (June), F225–F243.

- Farrell Joseph and Garth Saloner (1985), 'Standardization, compatibility, and Innovation', *Rand Journal of Economics*, 16, 70-83.
- Gardey, Depphine (1998), "The Standardization of a Technical Practice: Typing (1883-1930)" *Reaux*, 6 255-81.
- Gomes, L. "Economists Decide to Challenge Facts of the QWERTY Story", *The Wall Street Journal* February 25, 1998
- Hossain, Tanjim and John Morgan (2009) "The Quest for QWERTY" *American Economic Review Papers & Proceedings*, Vol. 99, No. 2, pp. 435-440.
- Katz, Michael and Carl Shapiro (1985), "Network Externalities, Competition, and Compatibility" *American Economic Review*, 75/3 424-440.
- Kirsch, David A. "The Electric Car and the Burden of History: Studies in Automotive Systems Rivalry in America, 1890-1996." PhD Dissertation, Stanford University, 1996 UMI 97-14137.
- Krugman, Paul (1994), *Peddling Prosperity*, New York: W.W. Norton.
- Lewin, Peter (2002), *The Economics of Qwerty: Papers by Stan Liebowitz and Stephen Margolis*, edited by Peter Lewin, Palgrave/NYU Press.
- Liebowitz, S. J. and Stephen E. Margolis (1990), "The Fable of the Keys," *Journal of Law and Economics*, 22, 1-26.
- _____ (1994), "Network Externality: An Uncommon Tragedy," *Journal of Economic Perspectives*, 8, 133-50.
- _____ (1995a), "Path Dependence, Lock-in and History," *Journal of Law, Economics, and Organization*, 11, 205-26.
- _____ (1995b), "Are Network Externalities a New Market Failure," *Research in Law and Economics*, 17, 1-22.
- _____ (1996), "Should Technology Choice be a Concern for Antitrust?" *Harvard Journal of Law and Technology*, 9, 283-318.
- _____ (1999), *Winners, Losers and Microsoft: Competition and Antitrust in High Technology*, Oakland: Independent Institute.
- _____ (1999a) "Causes and Consequences of Market Leadership in Application Software" (April 24, 1999). Available at SSRN: <http://ssrn.com/abstract=165069>.
- Navy Department (1944), "A Practical Experiment in Simplified Keyboard Retraining—A Report of the Retraining of Fourteen Standard Keyboard Typists in the Simplified Keyboard and a Comparison of Typist Improvement from Training on the Standard Keyboard and Retraining in the Simplified Keyboard." Department of Services, Training Section. Washington, D.C.: Navy Department, Division of Shore Establishments and Civilian Personnel.
- Postrel, Steven R. 1990. "Competing Networks and Proprietary Standards: The Case of Quadraphonic Sound," *Journal of Industrial Economics* 39, 169-185.

- Puffert, Douglas J. (2000), "The Standardization of Track Gauge on North American Railways, 1830-1890," *Journal of Economic History*, 60, 933-60.
- Ratchford, Brian T., Steven M. Shugan, David J. Reibstein, Peter E. Rossi, Jennifer Brown And John Morgan, Gerard J. Tellis, Eden Yin, And Rakesh Niraj (2009) "Commentaries and Rejoinder to 'Does Quality Win? Network Effects Versus Quality in High-Tech Markets'" 46 *Journal of Marketing Research* 150-162.
- Reinstaller, Andreas and Werner Hölzl 2009, "Big Causes and Small Events: QWERTY and the Mechanization of Office Work," *Industrial and Corporate Change*, 18, 999-1031.
- Strong, E.P. (1956), A Comparative Experiment in Simplified Keyboard Retraining and Standard Keyboard Supplementary Training, Washington, DC: U.S. General Services Administration.
- Tellis, Gerard J., Yiding Yin, and Rakesh Niraj (2009). "Does Quality Win? Network Effects versus Quality in High-Tech Markets." 46 *Journal of Marketing Research* 135-149.
- Williamson, Oliver E. (1993), "Transaction Cost Economics and Organization Theory," *Industrial and Corporate Change*, 2, 107-56.