0770
PATH DEPENDENCE

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Abstract

What role does the past play in current economic conditions? Economic models usually determine equilibrium ending points without concern for intermediate disequilibrium conditions or the prior history of the system. That the past does play some role is obvious, but the nature of its impact requires careful delineation. Some path dependence theorists have argued that past decisions might have locked-in certain inferior outcomes. In making sense of this claim particular attention needs to be paid to the meaning of 'inferior'. Upon investigation, such claims have been found to be without empirical support (in private markets) and based on fairly narrow theoretical assumptions. In nonmarket contexts less is known.

1. Introduction

Most generally, path dependence means that where we go next depends not only on where we are now, but also upon where we have been. History matters. Stochastic processes are path dependent if they exhibit memory: The probability distribution for the process at time $t+1$ depends upon more of the history of the system than just its state at time t.

As it has recently been applied in economics, path dependence means that equilibrium allocations depend on history. Economic allocations that are path dependent could not be predicted by knowledge of the efficient allocations, or the conditions that determine the efficient allocation, alone (Arthur, 1989). An expectation of path dependence accordingly is in conflict with economic models

that derive an equilibrium without taking account of the process leading to equilibrium.

Path dependence has a natural appeal. How could an outcome not depend upon the events that occur in the process of adjustment to equilibrium? The usual answer is that small variations in adjustments are averaged out, or countered, under the influence of the forces tending toward some determinate equilibrium. To take a familiar example, we expect price and quantity to adjust toward the supply-demand intersection, even if price adjustment were momentarily misdirected. Path dependence arguments introduce conditions under which correcting adjustments are not inevitable and they appeal for attention to the peculiarities that may unravel the predictability suggested by conventional equilibrium models. As we discuss below, however, this appeal must be countered by the recognition that any theory is a simplification of reality. So it remains a crucial question whether theories that ignore the sequence of events leading to equilibrium are ignoring something important.

The phrase 'lock-in by historical events', (Arthur, 1989) offers what is perhaps the best expression of the alleged importance of path dependence for economics. Lock-in has special meaning here. In some sense, of course, we are always locked in to a number of things; to eating, breathing, and remaining in our solar system to name three. But this is not what lock-in means in this literature. The lock-in in path dependence is a lock-in to something bad, or at least a lock-out of something better. It constitutes an inferior economic outcome such as an inferior standard or product where superior alternatives exist, are known, and where the costs of switching are not high.

These historical events of interest, in Brian Arthur's terminology, are 'small' or 'insignificant'. The insignificance of these historical events is not their effects - for their consequences are alleged to be large - but rather that they may seem inconsequential at the time they occur. There is an implicit allegation that such events are neither inevitable, in which case they might be taken as instances of the stinginess of nature, nor the product of significant conflict or deliberation, in which case they are the avoidable consequence of human folly. As we will elaborate below, a part of the appeal of the path dependence literature is the implicit allegation that these lock-ins, these bad economic outcomes, are avoidable by small but prudent interventions.

Path dependence is an idea that spilled over to economics from intellectual movements that arose elsewhere. In physics and mathematics the related ideas come from chaos theory. One potential of the non-linear models of chaos theory is sensitive dependence on initial conditions: determination, and perhaps lock-in, by small, insignificant events. In biology, the related idea is called contingency - the irreversible character of natural selection. Contingency implies that fitness is only a relative notion: it is not survival of the fittest possible, but only of the fittest that happen to be around at the time. Scientific

popularizations like James Gleick's book *Chaos*, Mitchell Waldrop's *Complexity* and Stephen J. Gould's *Wonderful Life* have moved these ideas into the public view.

While the warm reception given to path dependence in the social science is due in part to the attention given to these related ideas in the physical sciences, the analogy is incomplete. If, for example, turtles become extinct, they will not reappear suddenly when circumstances change to make it advantageous to have a shell. But if people stop using large gas guzzling engines because gasoline has become expensive, or extend patent protection to the 'look and feel' of software, they can always revert to their old ways if they came to regret the switch. Stephen J. Gould, who has made the affirmative case for contingency in biological evolution, nevertheless has noted the limitations of the analogy to social evolution. What may have also been lost in social sciences' borrowing of this concept are the active debates in the real sciences about the generality or applicability of chaos and contingency. Christian de Duve (1995), for example, argues that contingency applies only within important constraints in biological evolution.

Similarly, path dependence and chaos have an apparent unity that may be misleading. In chaos theory, small events or perturbations do tend to cause a system to evolve in very different ways but the system never settles down in any repeatable path or fixed equilibrium. The essence of the 'chaos theory' is that this seemingly endless pattern, which never finds an equilibrium, is not random but rather has a determinate structure. Path dependence in economics has imported the view that minor initial perturbations are important, but has grafted this on to a theory where there are a finite number of perfectly stable alternative states, one of which will arise based on the particular initial conditions. The potential for never-ending 'disequilibrium' that seems the essence of chaos theory is thus missing from the economic analysis of path dependence.

Path dependence challenges some parts of the law and economics literature. Some of the influence of economics on legal reasoning comes through efficiency results, or at least expectations of efficiency. To take one example, support for privity in contract can be found in economists' arguments that individuals' maximizing actions have the effect, under certain conditions, of maximizing total wealth. Path dependence (in its strong forms) is a challenge to these arguments. For the law itself, path dependence may seem self evident, given the role of precedent. In fact, those who have put forward the view that the law may tend toward efficiency have borne the burden of proof that precedent - or path dependence - would not overwhelm other factors. So for the law, what has seemed to require special argument is the absence of path dependence, not its presence. For this reason, the empirical issue of path dependence in market-based choices may be of particular importance for law and economics. If path dependence can interfere with efficiency even where

precedent does not play an explicit role and where we might expect evolution toward efficiency, such influence would appear magnified in the law, where precedent has such an explicit role.

In the remainder of this entry, we examine the theoretical and empirical claims of the economic literature on path dependence. We start with a simple example of path dependence, offered to help fix ideas. Following that, we offer a taxonomy of path dependence claims that draws on our article in the *Journal of Law, Economics and Organization*. In our view, some of the confusion around path dependence has resulted from a failure to distinguish among types of path dependence claims. We offer a remedy here. Following that, we present a discussion of the means by which market behaviors would tend to unravel instances of path dependence that constitute inefficiencies. The possibility that profit-seeking activities may be able to undo harmful path dependence reduces the issue to an empirical one: Are there documented instances of harmful path dependence? We close on that issue.

2. The Allegation: The Inefficiency of Path Dependence

The allegation of path dependence, as it addresses the workings of laissez-faire markets, is that market choices can stick us on undesirable paths. Once we are stuck in such a rut, individual decisions are the best we can manage only from the rut in which we find ourselves. Accordingly, for any allocation decision that might be susceptible to path dependence, we lose the usual presumption that individual choices lead to an optimal outcome. Consider the following example of a choice that could be subject to path dependence. Suppose that it is important that we all drive on the right side of the road, unless we all drive on the left. Assume also that it matters fairly little which convention we adopt but that most of us would prefer a convention of right-hand-side driving. Suppose further that one early driver is observed driving on the left-hand-side of the road. (Perhaps he was avoiding a puddle from a leaking horse trough.) Others who were planning to drive make a quick determination that left-hand-side driving, though mildly objectionable, will be the safe way to go. Those drivers are also observed driving on the left, which causes still more left-hand-side driving, and so on. Notice then that *it could happen that* we each prefer to drive on the right, but that each of us ends up driving on the left. Each agent behaves in a privately optimal way, given his circumstances, but the aggregate outcome is inferior to a seemingly feasible alternative.

As we will see when we examine these issues in detail, the phrase 'it could happen that' is a crucial one. That something could happen does not mean that it does happen. Before we can get to that, some definitions.

3. Definitions of Path Dependence

There are three possible efficiency outcomes where past conditions or decisions exhibit a persistent influence on a dynamic process. First, such persistence might do no harm. That is to say, an initial action does put us on a path that cannot be left without some cost, but that path happens to be optimal (although not necessarily uniquely optimal). For example, a capricious decision to part one's hair on the left may lead to a lifetime of left-side parting, but the initial urge to part on the left might capture all there is to be taken into account. On a grander scale, our decision to use a particular system for powering the machinery in a plant may be a controlling influence for decades, but the long-term effects of the decision may be fully appreciated by the initial decision maker and fully taken into account. We have used the term *first-degree path dependence* to indicate instances in which persistence of prior conditions or decisions exists, but with no implied inefficiency. This taxonomy of path dependence claims appears in our 1995 paper in the *Journal of Law, Economics and Organization*. Mark Roe's 1996 *Harvard Law Review* paper also offers a related categorization of path dependence. In Roe, path dependence can be weak (the efficiency of the chosen path is tied with some alternatives), semi strong, (the chosen path is not the best but not worth fixing, or strong (the chosen path is highly inefficient, but we are unable to correct it).

Since information is always imperfect, a second possibility arises. When individuals fail to predict the future perfectly, it is possible, even likely, that decisions appearing efficient *ex ante* may not always appear to be efficient *ex post*. Here the inferiority of a chosen path is unknowable at the time a choice is made, but we later recognize that some alternative path would have yielded greater wealth. In such a situation, which we have termed *second-degree path dependence*, persistence of prior conditions or decisions leads to outcomes that are regrettable and costly to change. They are not, however, inefficient in any meaningful sense, given the assumed limitations on knowledge.

Related to this second type of path dependence is *third-degree path dependence*. In third-degree path dependence, persistence leads to an outcome that is inefficient - but in this case the outcome is 'remediable'. That is, there exists some feasible arrangement for recognizing and achieving a preferred outcome, but that outcome is not obtained. Williamson (1993b, p. 140) offers the term 'remediability' to describe the condition that such feasible alternatives exist, and urges remediability as the appropriate standard for public policy discussion. Similar positions have been argued by Demsetz, Coase, Calabresi and Dahlman, among others. In the framework that these authors have advocated, market failure is not demonstrated unless a specific policy recommendation can be shown in which the benefits exceed the costs, including all of the administrative costs of the policy. For actual policy purposes, it of

course makes a difference whether the remediation remains possible: lost opportunities in the past are of not interest. But for the consideration of market failure, an opportunity for remediation in the past is of at least academic interest.

The three types of path dependence make progressively stronger claims. First-degree path dependence is a simple assertion of an intertemporal relationship, with no implied claim of inefficiency. Second-degree path dependence stipulates that intertemporal effects propagate error. Third-degree path dependence requires not only that the intertemporal effects propagate error, but also that the error was avoidable.

The essence of the distinction between third-degree path dependence and the weaker forms is the availability of feasible, wealth-increasing alternatives to actual allocations, now or at some time in the past. The paths taken under first- and second-degree path dependence cannot be improved upon, given the available alternatives and the state of knowledge. Third-degree path dependence, on the other hand, supposes the feasibility, in principle, of improvements in the path taken.

The existence of first- and second-degree path dependence is not in dispute. Clearly, this form of path dependence is very common. They are a reflection of ordinary durability and they have long been reflected in economic modeling. First-degree path dependence is recognized, for example, when we acknowledge that Robinson Crusoe and Friday may choose to make provision for the future. Ordinary durability installs (at least) this kind of persistence. Economists consider second-degree path dependence when we study decision making under uncertainty. While it may be of interest to identify these instances of persistence, first- and second-degree path dependence do not constitute a challenge to standing efficiency claims.

For these reasons, it is not surprising that the main focus of this literature rests on third-degree path dependence. The claim that the predictions of efficiency in standard economic methodology are likely to be wrong is a bold claim. Naturally, it is an empirical issue whether the path dependence literature acknowledges something important that neoclassical economics neglects by focusing on equilibrium positions rather than on the path toward equilibria. Some of the most prominent examples in this literature feature specific claims of inefficiency. For example, listen to Paul David: 'The accretion of technological innovations inherited from the past therefore cannot legitimately be presumed to constitute socially optimal solutions provided for us - either by heroic enterprises or herds of rational managers operating in efficient markets' (1992, p. 137).

Since it is only this third form of path dependence that can be understood as market failure, it is important to maintain the distinctions among these various forms. One must take care not to extend the plausibility of instances of ordinary durability - first- and second-degree path dependence - to third degree claims.

4. What forms of path dependence appear in the literature?

Brian Arthur's (1989) consideration of path dependence gives us the phrase of 'lock-in by historical events'. In his examples of the workings of positive-feedback models, which we examine in detail below, he finds that path inefficiency is possible where there are increasing returns. Arthur's version of path dependence is the third-degree form - so long as the information regarding the returns to each choice is available to relevant decision makers.

Thomas Schelling anticipated some of the kinds of problems that are considered in the path dependence literature. He discusses as 'interactive behaviors' problems in which outcomes depend heavily on the order in which actions occur. Inferior outcomes may prevail in these cases, even in the face of known preferred alternatives, illustrating the third-degree form (1978, pp. 36-8). Shelling offers these cases, however, as examples of nonmarket behavior, and he also notes that market institutions often arise as remedies for these problems (p. 33). Elsewhere he acknowledges the unfeasibility of some hypothetical improvements (p. 132).

The archetypal allegation of path dependence is the configuration of the typewriter keyboard. David's (1985) presentation is largely responsible for introducing this story to economists. According to this story, the standard 'QWERTY' keyboard arrangement, introduced in the 1870s, is dramatically inferior to an arrangement offered by August Dvorak in the 1930s. We are, however, regrettably locked into the inferior arrangement by a coordination failure: no one trains on the Dvorak keyboard because Dvorak machines are hard to find, and Dvorak machines are hard to find because no one trains on Dvorak keyboards. The process is said to be path dependent in that the timing of the adoption of QWERTY, and not its efficiency, explains its survival.

Some of David's claims for this case do not go beyond first-degree path dependence. Most readers will not question the observation repeated in David that 'One damn thing leads to another' (David, 1985, p. 332), because it asserts no more than first-degree path dependence. But David makes stronger claims. In accepting and repeating the claim that the cost of retraining in Dvorak is recovered ten days after the end of training (p. 332), for example, he positions the QWERTY case as an active example of third-degree path dependence. David's 1985 paper concludes: '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' (emphasis in original). We stay with the wrong keyboard, according to David, not because sunk investments in QWERTY make the switch to the Dvorak arrangement an inferior choice, but because of 'decentralized decision making'. This attribution of the error to decentralized decision making clearly suggests that alternative, presumably centralized, decision mechanisms would

correct this error. This is a third-degree claim. David's reader is likely to find the claim of path dependence in the third-degree form to be more palatable because of his earlier establishment of weaker forms of path dependence.

Paul Krugman has offered industrial location as an example of inefficient path dependence. If there were economies of having several firms in the same industry produce at a single location, we would expect firms to congregate somewhere. It could happen that firms simply congregate around the first location at which a plant is established. In such a circumstance, there would be no reason to think that the location chosen by such an industry is efficient. Krugman uses the example of the accumulation of carpet manufacturing firms around Dalton, Georgia (this city is the center of carpet production in the United States; Krugman offers it as an example of path dependence and as an example of the defects of traditional economic models). In such cases, it is argued, economics does not tell us which location would be chosen for an industry, and that it would only be by the sheerest of coincidences that the choice of location for a single plant would turn out to be the efficient location for an entire industry. There are several problems with this argument. First, there are some reasons to think that the first firm at a particular location would have chosen a location that is congenial to its industry. Second, most industries have multiple production sites, and therefore there would be competition among these candidate sites as a focus for industrial agglomeration. (For example, many carpet plants operate successfully in locations outside of Georgia, both in the Southeast and elsewhere.) Finally, locational choices may often involve a choice among a number of equally efficient alternatives. The fact that economics cannot explain the choice of a particular location over equivalently attractive alternatives is no evidence against the efficiency of the chosen outcome.

Path dependence along with the QWERTY story have moved out of academic writing and into the arena of public policy. In the *Los Angeles Times* (October 5, 1995), Steve Steinburg writes, regarding the adoption of an internet standard, '[I]ts all too likely to be the wrong standard. From Qwerty to Dvorak keyboards, to Beta vs. VHS cassettes, history shows that market share and technical superiority are rarely related'. In *The Independent* (September 5, 1995) Hamish McRae discusses the likelihood of 'lock-in' to inferior standards. He notes the Beta and VHS competition as well as some others, then adds, 'Another example is MS-DOS, but perhaps the best of all is the QWERTY keyboard. This was designed to slow down typists ... .' In *Fortune* (May 15, 1995) Tim Smith reports that QWERTY was intended to slow down typists, and then notes, 'Perhaps the stern test of the marketplace produces results more capricious than we like to think'. In a long feature series in the *Washington Post* (November 13, 1995), Steve Pearlstein argues that modern markets, particularly those linked to networks, are likely to be dominated by just a few firms. After introducing readers to Brian Arthur, he states, 'The Arthurian

discussion of networks usually begins at the typewriter keyboard'. The QWERTY story has also been published in the *New York Times*, *The Sunday Observer*, and *The Boston Globe*, *The Encyclopedia Britannica*, and broadcast on PBS's Lehrer news hour. The story can be found in two very successful economics books written for laymen; Robert Frank's and Philip Cook's *Winner Take All Society* and Paul Krugman's *Peddling Prosperity*, where an entire chapter is devoted to the 'economics of QWERTY'. It also figures prominently in Dixit and Nalebuff's *Thinking Strategically* and appears in some of Stephen J. Gould's writings.

These popularizations generally constitute the third-degree form. For the academic writings as well, the simple observation of durability conveys little surprise. These are interesting tales precisely because they are tales of things gone wrong.

5. Market Actions and Path Dependence

We start with a simple numerical example of path dependence as an illustration of the basic case. Table 1 is reproduced from a 1989 paper by Brian Arthur that is often credited with starting the whole discussion. The table is the basis for an exercise by which Arthur seemingly demonstrates the likelihood of unsatisfactory lock-in where there are increasing returns.

Table 1
Adoption Payoffs

Number of Previous Adoptions	0	10	20	30	40	50	60	70	80	90	100
Technology A	10	11	12	13	14	15	16	17	18	19	20
Technology B	4	7	10	13	16	19	22	25	28	31	34

The story that goes with the table is that there are two technologies that are in competition with each other. A would-be adopter arrives on the scene and chooses between technologies A and B. Assume for now that an adopter receives a payoff (value), as shown in the table, that is determined by the total number of adopters of a given technology. So, for example, if there are 21 adopters of technology A, each would enjoy a payoff of 12. The payoffs increase with the number of adopters, which incorporates the increasing returns assumption. These increasing returns might be due to either economies in

production, or network effects. (Network effects occur where the value of a product to a user increases as more consumers use the product.)

Arthur uses the table to illustrate the likelihood of undesirable lock-in. The first adopter on the scene, choosing between a payoff of 10 with technology A and a payoff of 4 with technology B, would be expected to choose technology A. The arrival of subsequent adopters will only serve to reinforce the advantage of choosing A. But notice that if the eventual number of adopters is large enough, technology B would yield greater returns. But the choices of individual adopters will lock us in to technology A.

Arthur's story of lock-in is simple - deceptively so. If we look at the table alone, it seems unavoidable that individuals' choices will lead to an irreversible choice of technology A and it seems undeniable that A is an unfortunate choice where the number of eventual adopters is large. The first adopter would rather have 10 than 4, and so would anyone else. We are locked in; the market fails. Each agent acts rationally, given the payoffs in the table, but as a group we end up with less than we might have had. Perhaps, the argument goes, some government action is needed to enforce a coordinated decision.

What is lacking from the table and is also lacking in the great outpouring of abstract modeling of path dependency, is an appreciation of both the variety of steps that people take to avoid such harms, and the restrictive conditions assumed in the table. These analyses make the common mistake of assuming that market organization and perfect decentralization are, or ought to be, the same thing.

Imagine for a moment that each of these technologies is owned, perhaps through patent or copyright. In that case, if the number of potential adopters is large, the owner of technology B would have a significant incentive to establish B as the technology of choice. Just as the owner of especially productive land is expected to capture the value of its advantages, the owner of a technology would be expected to capture the advantages that it offers over the next best alternatives. Given that, it is worthwhile for the owner of technology B to cut prices for early adopters or provide other incentives to induce adoptions of B. While the owner of A will have similar incentives, the total wealth potential of technology B is greater, so B would be able to offer greater incentives to become the technology of choice, under the assumption that B is the technology capable of yielding greater total benefits. Alternatively, if the technology is not owned, it would pay all would-be adopters to enter agreements to adopt the preferred technology.

More generally, the inefficiency that seems inescapable in the table is a profit opportunity for someone who can figure out the means to move the outcome from A to B and appropriate the difference. Such entrepreneurship can take various forms, some of which are familiar. Where a technology is not patentable or otherwise ownable, a firm may be able to create a format or a

variant of the technology that is. Firms can advertise, they can lease out the goods that implement the technology, they can enter strategic alliances. On the consumer side, a large user of a technology may be able to profit from adopting technology B regardless of the choices of other users. For example, large firms with numerous typists would have switched to Dvorak if Dvorak really did offer significant advantages.

The model that gives us lock-in from the numbers in the table not only reduces producers to the role of mere spectators, but it also assumes that consumers have no foresight. For if consumers were aware of the entire table, all that is required to prevent lock-in to an inferior alternative is that adopters can make reasonable forecasts of the number of eventual adopters. If, for example, early adopters know that they will be joined by 100 more, they will see that everyone will be better off with technology B. The latecomers will see it that way too, and the early-comers know it. (For a more complete discussion of this example, including an alternative interpretation of the table, see our 1995 paper.)

The kind of foresight that we are talking about here is not the domain of gifted visionaries. It is the kind of foresight that led consumers to buy an FM radio (as opposed to AM) in the early 1960s, cassette players in the 1970s (as opposed to eight-track), and CD players in the 1980s (as opposed to analog phonograph recordings). It leads newlyweds to buy a service for eight even when they do not yet know three other couples in town. And in 1990, it led consumers to buy Windows-based computers even when most machines were still DOS-based .

Finally, this model of lock-in also imposes certain other theoretical restrictions that may or may not commonly occur in the world. For example, to obtain the lock-in that Arthur demonstrates, the technology that offers smaller benefits at low levels of use must enjoy greater economies of scale. That is, the returns functions must cross, or initial consumer decisions will not put us on wrong paths. Since changes in payoffs must be due to economies of scale or network effects, it must be presumed that these influences differ across technologies. While it is certainly possible that this could occur, the requirements for lock-in are far more stringent than might appear upon a casual reading. In particular, it would seem that network effects would most likely exert the same influence on either of two rival standards or technologies.

6. Cases

The extensive theoretical literature on path dependence formalizes the following type of claim: it is possible to specify models in which right-hand-side driving is widely preferred, but nevertheless we all end up driving on the left. Such models must always include assumptions, explicit or not, about

expectations, ownership, information, network effects, production economies, communication, the possibility of side payments, the presence of large users and, more generally, entrepreneurship. Many of these are simply ignored, which is to say they are implicitly assumed away. The question then becomes whether this particular abstraction of reality captures what is important about the kinds of choices that path dependence is said to address. We are left then with an empirical question.

For empirical support, the literature of path dependence draws repeatedly on the same handful of stylized cases based on the popular histories of some well-known competitions between competing technological developments. First and foremost is the aforementioned story of the typewriter keyboard. In second place in this cannon is the competition between the Beta and VHS videotaping formats. After that is the eclipse of the Macintosh operating system by Microsoft's Windows.

Our paper 'The Fable of the Keys' (Liebowitz and Margolis, 1990) presents evidence on the typewriter keyboard story. In short, the received history is that the now-standard QWERTY keyboard arrangement is inefficient (some argue deliberately so) and that the Dvorak keyboard is known to be better. Our research shows that most of the claims for the superiority of the Dvorak keyboard can be traced to Dvorak's own writings. An often mentioned 'Navy Study', purporting to demonstrate the superiority of Dvorak, turns out to have been supervised by a Lieutenant Commander August Dvorak. A reading of the Navy study reveals that it was transparently rigged in favor of the Dvorak arrangement. In addition, a number of studies, using various methodologies, indicate that Dvorak offers little or no advantage over the QWERTY arrangement.

The allegation regarding the Beta and VHS competition is that the Beta format was superior, but that an early lead for VHS, strong producer alliances and better marketing led consumers to forsake their preferred alternative in order to be compatible with the majority of users. Simple versions of this history often ignore the fact that Beta had a two-year head start on VHS. Also overlooked is the fact that Sony, the creator of the Beta format, took great pains to try to forge a producer alliance, first offering its machine to the creators of VHS and then offering its machines to other Japanese and American producers, well before VHS had any significant market share. Beta's early adoption by Sanyo, Toshiba and Zenith runs counter to the claims that Sony was not interested in partners. Sony's failure to attract RCA to its coalition, however, gets to the true heart of the matter. Beta and VHS had almost identical performance, owing to common technological roots including the joint production of a previous generation of machines. Sony chose a small cassette for Beta, limiting the recording time, while Matsushita (the owner of JVC, the nominal creator of VHS) chose a larger cassette and a longer taping time. In negotiations, RCA told Sony that it preferred VHS since at that time Beta allowed recording time of only one hour, insufficient for movies or football

games. Sony slowed down the tape, allowing the taping of two hour programs, albeit at lower quality. Matsushita in turn slowed down VHS to get four hours of taping time, and RCA entered an agreement to market the four-hour VHS machine. RCA's judgement that longer taping time was more important to consumers than smaller cassettes appears in retrospect to be correct. Everywhere that consumers had a choice they overwhelmingly chose VHS even though the price differential was negligible (RCA came in with a startlingly low $1000 price, but this was matched by Zenith's $996 price within the week). Picture quality seems not to have been the issue either. *Consumer Reports* product testing at the time indicated no clear advantage in picture quality for either format, finding VHS better in two tests, Beta better in one, and a tie in another (Klopfenstein, 1989, p. 28).

What this case actually demonstrates is not lock-in but rather the ability of markets to facilitate a switch from one path or standard to another. In spite of Beta's two-year head start, the market shifted very quickly to a format that offered an advantage to consumers. It is noteworthy that broadcasters eventually standardized on the Beta format. The main difference between the formats, other than the size of the cassette, is the way the cassette is threaded. The Beta method, although more complicated, offers some advantages in editing videotape and in special effects. This advantage is unimportant to most home users, but is important to broadcasters. Broadcasters and home users rarely exchange video tapes, so there is little benefit for compatibility between the two. It is interesting, therefore, that professional broadcast users standardized on Beta, which is advantageous to them, and home users adopted VHS, which, with its longer taping time, is preferable to them.

The third of these path dependence stories is computer operating systems. It is sometimes claimed that although Microsoft operating systems are inferior to the Macintosh operating system, Macintosh failed because consumers were so locked-in to DOS that they would not make the switch to the better system. This claim requires close examination along several dimensions. First, the superior operating system is not the one that is theoretically ideal, but the one that is most efficient given the cost of the hardware required to run it. That is, economic efficiency is what counts, not some form of engineering efficiency. When DOS was king, computer memory was expensive and processors were slow. The graphical interface of the Macintosh required far more computing power to update than the DOS interface, on the order of fifteen to one. To take advantage of graphical documents required much processing and storage capacity, making it more expensive to get reasonable performance from a Macintosh machine. As the price of memory fell and processors became faster, the DOS operating system took on the features of the Macintosh, until at the present time they (Windows95 and the Macintosh) are almost identical in functionality for the typical consumer. Often overlooked is the fact that the

better operating system, the graphical operating system, did win, when it was justified by the cost. Again, it is worth noting that graphics professionals, for whom graphical processing was critical even at very high prices, moved to the Macintosh early on, when there was no good DOS alternative. That continues to be the market where the Macintosh has its greatest market share.

Van Vleck (1997) digs deeply into the claim, longstanding in the literature of economic history, that the British use of a small coal car (compared to the US and Germany) was an example of persistence of technological backwardness; a kind of path dependence. Van Vleck shows rather convincingly that the small coal car was an efficient response to differences in prevailing conditions in Great Britian.

Of particular relevance for law and economics is work by Bruce Kobayashi and Larry Ribstein on the adoption of uniform laws by states. For certain areas of the law, particularly where laws effect dealings with outsiders, standardization of statutes is efficient. Kobayashi and Ribstein (1996) studies the adoption of statutes that allow limited liability companies and find that while there are strong tendencies toward uniformity, the first form of a provision is not particularly to become the standard form. Again this is contrary to an expected influence from path dependence. In a related paper, Ribstein and Kobayashi (1996) do find evidence of an influence of efficiency in states' tendencies regarding uniformity of statutes. They show that uniformity is much more likely to be found in those areas of the law in which uniformity is particularly advantageous.

7. Path Dependence Outside of Markets

Our attention has been largely limited to the role of path dependence in market choices. Our observation is that where feasible improvements to an allocation can be identified, private actors will attempt to engage in exchanges that will allow them to profit from accomplishing these improvements. We do note, however, that many social choices do not take place in markets, and in fact may not even be recognized explicitly as choices.

The choice of religious and social institutions does not take place in an explicit market. The choice of government, for much of history, has not even been a choice for individual citizens. The institution of slavery was not a voluntary transaction. In these cases, the forces that would normally promote an efficient solution in the market do not necessarily come to the fore. A lack of ownership of alternative institutions is one problem, but a more important and fundamental problem is the absence of voluntary, feasible transactions. If the state or military controls the proceeds from productive activities, there may not be a feasible way to wealth-increasing improvements, since the beneficiaries can not write enforceable contracts to 'pay off' the despots who control the

system. Where there is no ownership of assets, or where coerced transactions are possible, the usual efficiency implications of market transactions can not be presumed. In such a world suboptimal solutions might have considerable permanence. For two differing analyses of path dependence for institutions, see North (1990) and Kiwit (1996). North's influential book, unfortunately, seems to accept at face value the claims of the path dependence literature that are based on false empirics.

These considerations have special importance with regard to path dependence and the law. For some aspects of the law, such as Antitrust, our finding that lock-ins are rare or nonexistent has fairly obvious implications. One of the concerns that has arisen in recent years, for example, is that high technology industries are particularly prone to path dependence because of network effects, and that therefore society might become ensnared in an inferior technology or standard. This argument has been made, both in the press and in arguments to the court, in connection with the many antitrust actions regarding Microsoft. Since these concerns can also be voiced for many technological standards, they might also made in connection with other antitrust cases, including the case that is currently being made against Intel. Our writing cautions that lock-in problems with choices of technologies or standards do not follow reliably, or even with much likelihood, from the simple presence of network effects.

The role of path dependence and lock-in is murkier in other areas of the law. With regard to statutory law, one might refer to legal institutions as a kind of market where suppliers of legal rules (legislators, judges) interact with demanders of these rules (constituents, plaintiffs). Yet even under this public-choice view of legal institutions, they are not the same as markets. The role of entrepreneur, of someone who can become rich by selling a better solution, does not have a complete analogy. Perhaps politicians do fill this role to some extent, but dollars and votes do not necessarily translate one to one. Nevertheless, the work of Kobayashi and Ribstein, cited above, shows that for several legal developments where path dependence might be expected to appear, it is not found.

Other writers, most prominently Richard Posner, have said much more regarding efficiency in the common law. Judges certainly could, where their decisions were not thoroughly circumscribed by precedent, seek out the global optima that are allegedly locked-out under theories of lock-in. But where legal efficiency is said to be the product of evolution to efficiency, the mechanisms for avoiding lock-in are less readily apparent. Indeed, litigators proposing novel legal theories may play the entrepreneurial role. Nevertheless, we are less sanguine that problems of path dependence are reliably avoided where law evolves from law and accordingly is less able to make the kinds of systematic jumps that allow markets to avoid lock-in.

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