

Back from the brink: Microsoft and the strategic use of standards in the Browser Wars

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Abstract

The thesis of the paper is simple. Rather than focussing on individual products in order to discuss technological competitions, we should focus on the systems to which a set of inter-related products belong. Accounts of individual products can, at best, provide us with a very partial account. At worst they may be completely misleading. This paper uses the Browser Wars as a test case for this thesis. The Browser Wars are probably the best-chronicled standards competition in recent history. Yet key aspects of this competition are not easily accounted for by the orthodox lock-in model – a model that considers competition between rival variants of a single product. There are two levels at which technological competition can occur. In addition to that between rival variants, there are battles for technological succession in which new technologies seek to displace established incumbents. Unfortunately the tools provided by the lock-in model are not suitable for this second type of competition. The paper therefore investigates the Browser Wars using a second framework. Based on Windrum (1999a), this framework integrates discussions of product competition with the broader literature on standards. As well as facilitating a discussion of firms' use of open and proprietary standards in technological competitions, the framework explicitly considers the systemic dimension of technologies. Two key aspects of 'context' are discussed; the interconnectivity between the products that comprise a system, and the degree to not just firms but also government and other actors shape the direction and rate of technological change. Indeed the paper suggests that government has an important role to play in providing a new regulatory framework that ensures competition and innovation on the Internet.

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1. *The Arthur lock-in model*

In 1995 Netscape appeared to be running away with the Internet. Supported by a 90% installed user base for its browser, Netscape was one of the fastest-growing software companies in history and the darling of Wall Street. Microsoft, by contrast, had virtually zero market share and many commentators were suggesting it would go the way of IBM before it - a Goliath that was unable to negotiate the new technological wave. Yet, by the end of 1998, the picture was reversed. Microsoft's had staged a dramatic comeback to claim a 50% market share while Netscape, now losing money at an alarming rate, was the subject of a successful take-over bid. How did this dramatic change in fortunes occur? And to what extent can lock-in theory help explain these events? If it is deficient, is there an alternative analytical framework that may help? These are the principal empirical questions addressed in this paper. In this section of the paper we outline the Arthur model of technological lock-in. Then, in section 2, we apply the model to the Browser Wars case.

Authors are apt to refer to 'a' formal model when discussing Brian Arthur's work on technological lock-in. This is, strictly speaking, incorrect because one can find three different models in Arthur's work. Historically, the earliest model is a random walk model with two absorbing barriers (Arthur, 1983). The second model, developed in association with Ermoliev and Kaniovski, is a Polya Urn model (Arthur, Ermoliev and Kaniovski, 1984; 1987) while the third model is a 45° random walk model (Arthur, 1986). The majority of authors, when discussing 'the' Arthur model, implicitly refer to the Polya Urn model. Arthur, however, appears quite happy to switch from one model to another. Indeed in his 1989 Economic Journal paper he employs all three models in order to highlight different aspects of his lock-in account of technological competition. There are good reasons, it should be said, why attention has focussed on the Polya Urn model. Firstly, Arthur claims that the results generated by the other two models are generalisable to a Polya Urn, thereby giving greatest weight to the Urn model. Secondly, and in no small thanks to the work of Ermoliev and Kaniovski, the Polya Urn model is the most rigorously developed of the three models. Thirdly, and perhaps most importantly, the AEK Strong Law (see below) is derived from the Urn model.

Following Arthur (1989), the gist of all three models can be captured by a formal adoption equation in which an individual selects between two rival variants of a new technology (A and B). This (s)he does by evaluating the payoff (Π) associated with each variant. The payoff at time t is

$$\Pi = X_i + r (n_i^t) \quad (1)$$

where X_i is individual i 's personal preference for a particular technology and r is a term that captures the increasing returns to adoption. The value of r is higher the greater the number of previous adopters (n_j) at time t . For example, the value of a telephone system to a user depends

on how many other users (s)he can communicate with. By contrast, X_i is an independent term indicating the hedonistic value an individual attaches to a technology, even when there are no other adopters.

The probability of adopting variant A at time t is

$$\Pr\{ X_A + r(n_A^t) \geq X_B + r(n_B^t) \} \quad (2)$$

Following Bassanini and Dosi (1998), this can be rewritten as

$$\begin{aligned} \Pr\{ X_B - X_A \geq r(n_A^t) - r(n_B^t) \} \\ = F\phi [r(n_A^t) - r(n_B^t)] \end{aligned}$$

where $F\phi ()$ is the distribution function $\phi^t = X_B - X_A$.

Arthur's main theorem, the AEK Strong Law of Path Dependency, can be derived from equation (2);

Theorem: If the improvement function r increases at least at rate $\varepsilon > 0$ as n_j increases, the adoption process converges to the dominance of a single technology, with probability one (Arthur, 1989).

This AEK Strong Law is the basic result which each of Arthur's models seeks to reveal. The system will lock in either variant A or B, producing a market monopoly. However, and this is the point that Arthur wishes to stress, when selection is frequency-dependent it is impossible to predict *ex ante* which variant of a new technology will be the winner. If the relative fitness of a variant depends on population shares (including that variant's own share) then the strategic choices of individual buyers are interdependent. Bandwagon effects can quickly spread as a result of changes in the behaviour of other adopters. As a consequence, selection in the models is non-ergodic and highly sensitive to initial starting conditions, the final outcome depending on the way in which adoptions are built up. Kirman (1997) notes that this path dependency depends on two features of these models. First, it can arise when there is an increasing size of population - the Polya Urn model, for example, assumes an indefinitely increasing population in order to establish asymptotic results. A second factor is the strictly sequential nature of decision-making. Bassanini and Dosi (1998) add that the AEK theorem only strictly holds when returns are linearly increasing and there is homogeneity of consumer preferences (or at least the degree of heterogeneity is small).

The combination of increasing returns to adoption and path dependency has a number of consequences for market-driven *de facto* standards. Arthur emphasises the extent to which small

historical events, (i.e. random and unpredictable) that occur in the early stages of a technology's history can fundamentally affect its development and diffusion. Such chance events can, Arthur stresses, easily lead to the selection of a sub-optimal technology. This analytical result seriously undermines the claim that the market mechanism will automatically select the variant that is optimal for a particular set of preferences and production constraints¹.

2. *A lock-in account of the Browser Wars*

Following David's seminal study of the QWERTY keyboard (David, 1985), the lock-in account has been applied to a number of product standards battles. Arthur (1988) has discussed the impact of small chance events (i.e. random and unpredictable) on the development of the car industry. At the turn of the century there existed three alternative technology options; petrol, steam and electric battery engine cars. Arthur provocatively argues that a key point event which turned the competition in favour of the petrol engine was an outbreak of foot and mouth disease in the US in 1914. This shut down the horse troughs from which steam cars drew their water, giving an important stimulus to petrol-driven designs. Two other standards battles cited by Arthur are the Sony Betamax vs. JVC VHS video recorder battle, and the IBM PC vs. Apple Macintosh battle. As with the QWERTY keyboard, there was a lock-in to a technology variant which, even at the time, was widely recognised to be the sub-optimal alternative. The lock-in model has been applied to a number of other standards battles. Lock-in theory has also become popular in the strategic management literature. Of particular note here are the collections of case studies by Peter Grindley (1992) and Steven Schnaars (1994). The empirical literature now covers a diversity of product and process technologies which range from magnetic resonance imaging (MRI), automated teller machines (ATMs) and CAT scanners to high definition television (HDTV), cordless telephones and light beer. As well as deepening the understanding of technological lock-in, this body of empirical work has brought the theory to a wide audience. At first sight the Netscape-Microsoft Browser War seems obvious candidate for a lock-in study. As well as being the most chronicled standards battle in recent history, it has attracted the attention of the US authorities, which have pursued a long and drawn-out antitrust lawsuit against Microsoft. Indeed US and European media frequently refer to lock-in theory when interpreting the issues of this case for their readership. It therefore seems an opportune moment to test appropriateness of the lock-in account.

The typical lock-in account proceeds in the following manner. It begins by defining the product under study, in this case the web browser. It then sets up a 'standards battle'. A particular date is given as marking t_0 . At t_0 there are n rival firms, each offering a rival variant of the product. There is usually little or no attempt to contextualise the battle beyond the leading protagonists (i.e. to discuss the broader commercial, social or political factors that shape events) or to consider how history prior to this date t_0 influences the strategies of the protagonists or in some other way affects the outcome. Rather, attention is squarely focussed on the competitive strategy that each firm pursues in order to win the standards battle. There then follows a detailed account of how the

¹ See Windrum (1999b) for a discussion of how this result undermined the proposition that there is an economic equivalent to R.A. Fisher's Fundamental Theorem of Natural Selection.

dynamics of increasing returns to adoption explain why one firm's strategy was more effective than its rivals and, thus, how the particular variant offered by that firm comes to dominate the market.

Let us consider what a lock-in account of the Browser Wars would look like. In this particular instance the battle is not quite over but all the other elements are in place. Furthermore, it is possible to indicate what the likely outcome will be. The web browser is a well-defined technological artefact. It is used to communicate over the Internet with Web servers using HTTP (HyperText Transfer Protocol). HTTP enables the user's browser to pull up information or else to 'surf' the Web. The basics of the browser are quite simple. When a user first opens his/her browser, the browser follows a link that reads a document written in the HTML language and displays this in a window. For example, let us say that you wish to read the electronic version of this document held on the MERIT website at `<http://meritbbs.unimaas.nl/>`. To access this document your browser will use the HTTP protocol to send a network request for this file to the web server where the document resides. The Web server will then respond to your browser's request and, by following the HTTP protocol, send this document to your browser. Your browser can interpret the HTML in the document and is able to display it on your screen.

While an important part of the underpinning technology of the Web was developed in Europe, the US quickly came to dominate and shape its commercial development. Two US corporations in particular, Netscape Communications and Microsoft, have significantly shaped the commercial development of the Web through their control of the browser platform. Neither company was the first to develop a commercial Web browser. That honour goes to the National Center for Supercomputing Applications (NCSA), who released its Mosaic browser in 1993. Mosaic was superseded by Netscape's rival browser. The beta version of Netscape Navigator 1.0 was released on 14th October 1994, with the final commercial version following on 15th December. Netscape Navigator 1.0 represented a significant achievement, both as a technology and for Netscape as a company. Founded on 4th April 1994 by Jim Clark and Marc Andreessen, the company's design team was able to develop and launch its browser within just six months². Netscape 1.0 was by far the best graphical interface platform around at the time, both in terms of its ease of use and its technical design. As well as being able to load graphic images faster than Mosaic (thanks to its innovative 'continuous document streaming' code), Netscape offered the user improved features such as easy-to-use navigation and new text formatting options. In subsequent versions of Navigator the company would add Frames, coloured backgrounds and many other features that are now considered a normal part of Web page design. In addition to having a superior product, Netscape effectively gave away Navigator 1.0 for free. As well as the beta test version being freely available, Netscape allowed companies and individuals to download the finished commercial version of Navigator 1.0 from the Internet free of charge³. By giving away a superior product, Netscape quickly captured the Web browser market.

The decision to give the browser away was a clever piece of marketing. Clark and Andreessen

² Originally called Mosaic Communications Corp., the company changed its name to Netscape Communications Corp. in November 1994 following a legal wrangling with NCSA over rights to the Mosaic name.

³ A charge was only made on those users wishing to receive a 90 day warranty and customer support.

were more interested in the profits generated by Netscape server software packages - for which it charged up to \$50,000 - than by royalties on the browser itself (Newman, 1997). They were well aware of, and drew lessons from, the example provided by the Microsoft's Windows operating system. They knew that getting designers to pay for server software would require building up a large installed user base, thereby locking the market into their particular Web browser. This they quickly succeeded in doing. By the time Netscape Communications Corp. became a publicly quoted company in August 1995, its browser was one of the fastest-growing software companies in history with a 90% share of the Web browser market. Amid investor frenzy, its share price rocketed from an initial price of \$14 to \$86 on the first day of trading, turning Clark and Andreessen into paper millionaires.

Equation (1) assists our conceptual understanding of the Mosaic-Navigator battle. While the Mosaic browser had an initial advantage in terms of its installed user base (r), Netscape was able to turn the market in its favour by satisfying personal preferences (X_i) for a superior browser technology. Indeed Netscape seems to provide a good example a company that has exploited the key principles of lock-in theory. In addition to strategically planning to establish a large installed user base, it has pursued a strategy of incremental innovation in order to extend its browser's functionality while enabling users to retain their core skills and knowledges. Surely Netscape, with an installed user base of 90%, had an unassailable position and this would be the end of the story? The answer, as we know today, was 'no'. Bill Gates' famous 'Pearl Harbour Speech' signalled the commencement of a second Browser War on 7th December 1995. It was one thing for Gates to proclaim that Microsoft would become a leading Internet player, it was quite another to realise this ambition. Microsoft was a late market entrant whose Internet Explorer (IE) browser was not on the market at time t_0 ⁴. What is more, Microsoft had showed little or no any interest in the Internet prior to Gates' speech. By the time it did act, Netscape had been left plenty of time to build up a large installed user base. Let us consider some of the key factors, or 'stylised facts', relevant to the Netscape-Microsoft battle. Thereafter we shall consider whether the lock-in model helps us understand this second series of events.

Two aspects of consumer demand greatly assisted Microsoft. First, users are loath to switch from the first browser they come into contact with. Once a particular browser is installed on a user's computer there needs to be a very good reason for him/her to download an alternative browser. Of the 7,000 respondents contacted by the 8th GVVU World Wide Web Survey in Autumn 1997, 72% stated they had never switched browsers. 81% of new users (defined as users with 12 months or less experience of the Internet) stuck with the first browser they came into contact with. The report suggests this rigidity is not due to difficulties in learning how to use a rival browser or to differences between the product features offered of rival browsers. Instead users are, in general, simply unwilling to invest time in searching for, and testing, alternative browser software. Moreover, new users' inexperience of the Internet appears to make them uneasy with even the idea of downloading software (including rival browsers) over the Internet. The second factor working in Microsoft's favour was the spectacular growth rate of the Internet, which

⁴ Netscape Navigator 1.0 was released in December 1994, version 1.1 in April 1995, version 1.2 in July 1995, version 2.0 in December 1995, version 3.0 in August 1996 and version 4.0 in June 1997. Microsoft did not release version 1.0 of Internet Explorer (IE) until August 1995, with version 2.0 following in November 1995, and version 3.0 in August 1996.

continues to double in size year upon year⁵. This provided ample scope for a late entrant, such as Microsoft, to drive a wedge between the existing generation of users (who had overwhelmingly chosen the Netscape browser) and the next generation of users. Potentially, at least, Microsoft could achieve parity in market share with Netscape within two to three years *provided* it could capture the majority of new users.

There were essentially three planks to the Microsoft strategy. First, effort was put into improving the quality of its IE browser so that it would at least approach the quality of the Netscape browser. Second, Microsoft made IE 3.0 freely available to both individuals and companies. This contrasted with Netscape who, by this time, was exploiting its market position and charging for its browser⁶. The commitment of Microsoft to establishing itself as a major Internet player was such that it was willing to sustain large losses in the short-run in order to gain market share. The sheer earning power of Microsoft meant it had no problem cross-subsidising these activities. This action alone may not have invoked the wrath of the US Department of Justice (DoJ), indeed Microsoft could justifiably claim that it was merely following Netscape's earlier example. However Microsoft's strategy did not end here. The third plank of its strategy was to control the key distribution channels through which new users acquire their first web browser. Evidence brought against Microsoft in the US antitrust lawsuit indicates it was well aware of the stickiness of user demand. It was also aware that most users were either acquiring their browser in a hardware or software bundle, or else through their Internet Service Provider (ISP) (Foley, 1998). Microsoft therefore sought to use its power within the computer industry⁷ to ensure its Internet Explorer was the first browser new users would come into contact with.

It was this third plank of Microsoft's strategy that brought it into direct conflict with the US authorities. Pressuring the leading OEMs (original equipment manufacturers) to automatically bundle IE 3.0 as a standard part of their PC packages invoked the first legal proceedings for anti-competitive practices in 1996. The release of IE 4.0 prompted a second antitrust lawsuit, this time brought by the US DoJ, in December 1997. Here Microsoft's attempt to integrate its browser into its Windows95 operating system was upheld as unfair competition. In addition to hardware and software bundling, Microsoft had acted to ensure IE would be the automatic default browser for subscribers to the major retail ISPs. The distribution of subscribers is highly skewed to four ISPs - America Online (AOL), Internet MCI, Microsoft Network and CompuServe - giving them a very powerful position within the market. Of these, AOL is easily the largest retail ISP with 14 million subscribers. Microsoft's strategy to control this particular distribution channel comprised two parts. The first part involved its heavily investing in Microsoft Network in order to establishing itself as a major ISP in its own right. The second part involved striking a series of exclusivity and cross-advertising deals with the other major ISPs. In exchange for Microsoft listing their services on its Windows95 Internet Connection wizard, the other ISPs agreed to offer IE as their standard default browser. A Senate Commerce Committee found Microsoft guilty of putting pressure on the large retail ISPs in promoting its IE browser. Yet, despite the Committee forcing Microsoft to abandon its ISP agreements in March 1998, IE remains the sole default browser offered by the top four ISPs (Newman, 1998).

⁵ See Windrum and Swann (1999) for a detailed discussion of this phenomenon.

⁶ Netscape subsequently reacted to Microsoft's move by similarly making its browser freely available.

⁷ 90% of all PCs sold work under one or other version of Microsoft Windows

This string of lawsuits proved were just a foretaste of the sweeping legal action brought against Microsoft by the US DoJ and 20 states on 18th May 1998. The central issue is again the extent to which Microsoft has exploited its powerful position within the computer industry in order to control the distribution channels through which users acquire their browser software. For example, DoJ Exhibit No. 233 - an internal Microsoft document titled "IE 5 OEM Marketing Plan" - discusses how exclusivity deals were to be struck with the top 10 PC hardware manufacturers in order to ensure the success of IE 5.0. The same document refers to a plan that would not only integrate IE with Microsoft's Windows98 operating system, but virtually every piece of Microsoft application software. This, the DoJ argues, threatens to eliminate any competition in the browser market because consumers will be unable to use many functions of Windows with anything other than IE. IBM, one of the few large ISPs still offering Netscape as its preferred browser, announced in September 1998 that it would henceforth only distribute IE. After examining Windows98, IBM strategy manager Adam Wong announced that "Windows Explorer and Internet Explorer are meshed... If you're in Windows Explorer [file manager] and you want to launch [a Web page in] Netscape, that ain't gonna happen" (quoted by Newman, 1998).

The DoJ antitrust lawsuits have been billed in the media as one of the most important anti-trust battles in history. But they have proved too little too late for Netscape. By the beginning of 1998 the 'smart money' was already riding on Microsoft to win the Browser War. IE's share of the market stood at 39% in January 1998, up from 21% in January 1997. While the number of computers installed with Netscape grew by only 33% during 1997, the number installed with IE had nearly tripled, indicating that Microsoft was indeed succeeding in capturing the vast majority of new users. Netscape's problems were confirmed when it announced a fourth quarter loss of \$88.3 million for 1997, bringing its total loss over the year to \$115.5 million. Unlike Microsoft, Netscape could not subsidise these losses with profits from elsewhere. The announcement of a decision to axe 400 jobs in January 1998 sharpened questions about Netscape's survival. In November 1998 the company was the subject of a successful take-over bid by America Online (AOL). The take-over is likely to mark the final chapter in the second Browser War. AOL is not interested in selling browser software. Moreover the lack of a standard browser platform, and the market uncertainty which this creates, is detrimental to AOL's main business interest, which is the development of e-commerce. The key attraction of Netscape for AOL was its Netcenter portal website. Netcenter's 9 million registered users are mainly business subscribers. This compliments AOL's 14 million subscription base, who are largely consumers. AOL-Netscape is easily the biggest portal on the Web - the site through which most people pass as they look for information or buy/sell goods. It has 50% more visitors than its closest rival Yahoo. AOL's interest in e-commerce means it will probably co-operate with Microsoft through standards bodies such as the International World-Wide Web Consortium (the W3C) to end the browser standards battle and establish a common browser platform.

3. *Empirical criticisms and extensions*

While the Arthur lock-in model assisted our understanding of the Mosaic-Netscape Browser War, it seems to shed very little light on the Netscape-Microsoft War. Microsoft - not exactly renowned for its ability to produce innovative products – did not succeed through the development of a superior browser technology. Indeed it has tended to offer an inferior technology at each turn. Versions 1.0 and 2.0 of its IE browser were essentially licensed versions of the old NCSA Mosaic technology and, as such, were inferior in quality to Netscape's Navigator 1.0 and 2.0. As well as being slower in its page display and image rendering, IE 2.0 did not provide support for three key features of Navigator 2.0 - frames, plug-ins and Java. Not surprisingly, the IE failed to make an impact on the market. The release of IE 3.0 did mark a significant improvement, although this was due to Microsoft's cloning of numerous Netscape features rather than through novel innovation. The general consensus is that Microsoft actually took a step backwards with IE 4.0, which was poorly designed and overly complicated to use. Matters have improved somewhat with IE 5.0, although there are few that would suggest that IE 5.0 is a superior product to Netscape's rival offering.

In itself the inability to explain the outcome of the Navigator-IE standards battle through the X_i term of equation (1) does not undermine the theory. Indeed, as section 2 noted, a major claim made by the theory's proponents is its discussion of how inferior technology variants can (and do) win standards battles through the externality r term of equation (1). Unfortunately, in the Navigator-IE case, Navigator started out with 90% of the installed user base. With this size of bandwagon already in place, Arthur's model does not assist in explaining how Microsoft managed to return from the brink of defeat. Is it perhaps that we are simply pushing the model too far and applying it to a situation for which it was not designed? The model, it should be remembered, was originally intended to describe technological competitions between contemporaneous and unsponsored standards that begin with roughly equal market shares. It was *not* designed to explain how late entrants use their control over distribution channels or some other factor to overcome the first-mover advantages of an earlier entrant. How can we respond to this problem? There seem to be two possibilities. One is to try to retain the lock-in story as a general heuristic while amending the model to accommodate what would otherwise be problematic facets of the case study. This option has been pursued by a number of writers. The other option is to look for an alternative conceptual framework that is more suited to the case study. In this section we explore the first response. In sections 4 and 5 we will explore the alternative response.

To begin with, the Netscape-Microsoft battle requires an examination of the particular demand conditions of the browser market between 1996 and 1998. First, there is an important distinction between the current installed user base and the rate of growth of the user base. If the user base is rapidly expanding, as it was in the browser market, then an initially large share of the installed user base - even a 90% share - is *no longer* a sufficient condition to ensure a technology lock-in through r . The second factor highlighted in section 2 is that influence of previous adopters n_i^t can be outweighed by other considerations. In this case it seems that end-users were quite happy to use whatever browser happened to come free with their PC (or else provided by their ISP).

Hence r was not so much effected by the existing installed user base as by Microsoft's ability to ensure that its browser was the one which automatically appeared on a new user's PCs. This enabled Microsoft to drive a wedge between the old and the new generation of adopters⁸. In order to accommodate this observation one can extend the Arthur model to include a second term in r representing the installed user base of Microsoft's PC operating system, such that $r (n_i^t + n_j^t)$. The payoff associated with a variant at time t then becomes

$$\Pi = X_i + r (n_i^t + n_j^t) \quad (3)$$

The result of adding n_j^t is rather dramatic. In effect we derive a new Urn model. It is very likely that this new Urn model will have completely different roots with, most probably, only one solution - a monopoly for Microsoft. This recognises the sheer market power and financial clout of Microsoft in relation to Netscape, since the absolute size of n_j^t is dwarfed by n_i^t . Regardless of the total share of n_i^t commanded by Netscape in 1995, it could not compete in the long-run against Microsoft's 90% share of n_j^t . While it is clearly possible to extend the Arthur model in this way, it is not very appealing from a theoretical point of view. Indeed this extension seems to raise as many questions as it answers. First, there is the question of how we define 'the market'. Equation (3) stretches the Arthur model by linking together the installed user bases of two markets; the browser market and the PC market. At what point should this end? Second, there is a more general question about how far one should accept making ad hoc extensions to a model. There is a danger that we may end up with as many ad hoc extensions as there are case studies. In elaborating a 'general model' that includes all possible extensions, we may end up with very complicated payoff functions that agents are unable to calculate in practice. With this thought in mind, it is perhaps an opportune moment to see whether an alternative framework exists that is more suited to this case study.

4. *An alternative framework: complex technological systems*

In this section we outline the model of technological succession discussed by Windrum (1999a). Thereafter we consider, in section 5, whether this conceptual framework can assist the discussion of the Netscape-Microsoft Browser War. Four features of the succession model distinguish it from the lock-in model. First, the principal research question of the lock-in model is competition between rival variants of a new technology. The principal research question of the succession model is how a new technology is able to unseat a well-established incumbent technology. The second distinguishing feature of the succession model is its systems focus. It examines 'complex technologies' that comprise a number of interrelated products. This system perspective gives rise to a third distinguishing feature: a discussion of conceptual frames (gestalts) that define a system

⁸ A number of the case studies conducted by Schnaars (1994) similarly highlight the importance of market power to control distribution channels. Schnaars identifies three key strategies (which may be used independently or in combination) by which late entrants can overcome the first-mover advantages of a pioneer; (1) offer lower prices than the pioneer, (2) develop a superior product, or (3) use their market power to overwhelm a weaker pioneer. Again, it is this third strategy that distinguishes the analysis from Arthur's model.

and the mechanisms that help link the system elements together. The latter considers the way in which artefact competition is related to a wider process of standards formation. Finally, the succession model considers how the selections made by a range of actors - not only economic (i.e. consumers and firms) but also political and other interest groups - shape the evolution of a complex technology.

Rosenberg (1982) observed that a product is rarely used in isolation. Typically it interacts with other products in order to deliver a final service to an end-user. Moreover, Rosenberg notes that clusters of new, interrelated technologies have marked important epochs in economic history. Discussions of the economic importance of clusters of new technologies have similarly been highlighted in the literature on economic long-waves that followed the work of Freeman, Clark and Soete (1982). The notion of inter-relatedness is the key defining aspect of a complex technology. A 'complex technology' is a 'system' that comprises a set of inter-dependent products that are jointly consumed. "The importance of these complementarities suggests that it may be fruitful to think... of these major clusterings of innovations from a systems perspective" (Rosenberg, 1982, p.59). The adoption of a systems perspective represents a major break with the vast majority of technology studies. Rather than thinking in terms of an isolated product, a system perspective forces one to consider the context of the product under study; notably the interdependencies that exist between it and the other products that form a complex technology.

The analytical level at which one defines a technology fundamentally affects the type of account that is developed. A systems perspective leads one to address a very distinct set of research questions to those addressed by the lock-in model. To begin with, there is the issue of mutual value relationships between the elements making up a complex technology. Obvious examples of complex technologies are telecomms and other IT technologies, where it is hard to even speak about the value of a particular piece of hardware or software without discussing the other elements to which it is connected. Second, compatibility issues are important, not only for producers but also for end-users. From the end-user's perspective, performance is not only dependent on the constituent components of a complex technology but also on the extent to which these are compatible with one another. Hence the perceived value of any individual component depends on how well it works with the other hardware and/or software components that make up the technology. At the time of purchase, a user may obtain these components together as a combined package or else (s)he may be able to purchase the components as separate items. Changes in the specification of one component can have a marked affect on the user's perceived value of the other components making up the technology. This interdependence of value for the end-user is distinct to the demand-side phenomena discussed by the Arthur lock-in model. As noted in section 3, there the end-user is unconcerned as to how the technology is produced or who produces it. This leads to a consideration of the supply-side features of a complex technology.

The production of a complex technology is very different to the textbook neo-classical representation in several respects. Firstly, there is marked difference in the industrial structures that are considered. Regardless of the number of firms that are present in a particular market (whether this be a single firm or a very large number of competing firms), the standard textbook model assumes that each firm is a vertically integrated producer. That is to say, each firm

produces all the components that make up a technological artefact. By contrast, the succession model discusses how innovation is conducted within a set of distinct but interdependent producers. Where a multiplicity of distinct firms and other agents shape the evolution of a complex technology, a single producer cannot entirely shape, by its own volition, an evolving technology. As Swann and Windrum (1998) observe, under these conditions invention and innovation becomes an explicitly collective phenomenon that is conducted by a network of related producers.

This mutual value relationship between inter-related products has important implications for the innovation strategy of these networked firms. The realised returns to the R&D of an innovating firm are clearly dependent on the R&D activities of other related firms, which may be beneficial or detrimental in their effect. This places on the agenda a strategic trade-off between co-operative and competitive behaviour between firms. It is important to emphasise that collective invention is not restricted to formal R&D collaboration between a number of firms. An important area of focus is the way(s) in which firms attempt to co-ordinate the supply and design of related components through procedures other than formal collaboration agreements. One avenue is the setting of common standards that facilitate compatibility between the component products and/or services that make up a complex technology (e.g. physical interfaces and communication protocols). Process standards governing the ways in which the component products are themselves produced (e.g. software languages and tools) can also play an important role in complex technologies. Responsibility for the formal codification and monitoring of these standards may be given over to an institutional body such as ISO, BSI and CEN.

This brings us to the relationship between market-driven *de facto* product standards and the technical standards *de jure* set by institutions such as ISO, BSI and CEN. Compatibility issues and product competition go hand-in-hand in technological competitions. While this is widely recognised and commented upon by authors writing on *de jure* and *de facto* standards, these literatures nevertheless remain largely separate⁹. Given the clear importance of all aspects of the standards setting process within complex technology systems, the succession model cannot avoid such an integration. Indeed this can be fairly said to be one of its novel features. Following Swann and Windrum (1998), we define standards as ‘a set of common features belonging to a group of products and/or services which benefit users because it facilitates compatibility between those components’. This broad definition encompasses the informal standards embodied in design conventions and the ergonomic ‘look and feel’ qualities of user interfaces as well as standards governing interface compatibility, communication protocols etc.

An important distinction is drawn between two types of technological competitions within the succession model; those leading to component replacement, and those leading to wholesale system replacement. Figure 1 illustrates the case of a component replacement within an existing technology system. The replacement of an existing element by a new element is an important means of incrementally improving the overall quality of a complex technology while retaining the other system elements. Here a common interface standard can play an important role in facilitating the process of incremental innovation. The ability to ‘plug in’ new elements avoids

⁹ Arthur, for example, at various times notes the overlap between the lock-in literature on product standards and the literature on *de jure* standards (e.g. Arthur, 1988, 1989). However he has not sought to integrate the two.

the need to re-engineer the elements that make up the product, significantly reducing the costs that would otherwise be associated with this form of incremental innovation.

Figure 2 illustrates the case where an established system is replaced by a new, alternative system. This second type of technological competition is far more likely to produce the economic discontinuities discussed by Schumpeter (1939). Wholesale system replacements are far more likely to produce radical disjunctures in learning, skills and competence bases – as well as a replacement of material artefacts and production processes, a technological succession implies the replacement of the knowledge and power (economic, social and political) associated with the old technology with new assemblages. A necessary condition for system succession highlighted by Windrum (1999a) is functional equivalence. Windrum and Birchenhall (1998) observe that a necessary condition for a sustainable market niche is the support of a distinct user group that is attracted by the functionality offered by a technology in use. Therefore for a technological succession to occur, adopters must be persuaded that the new technology can better fulfil the product or process function of the incumbent technology.

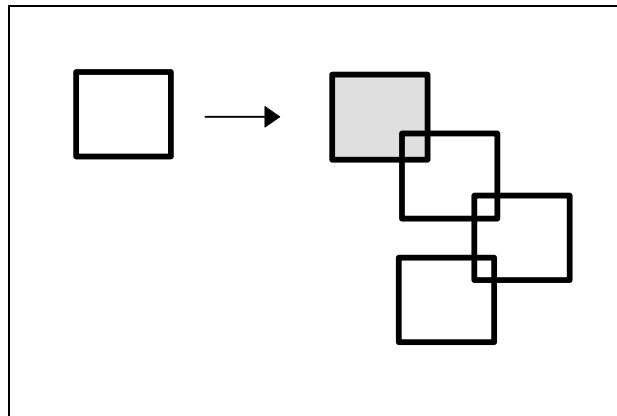


Figure 1. Component replacement within an existing system

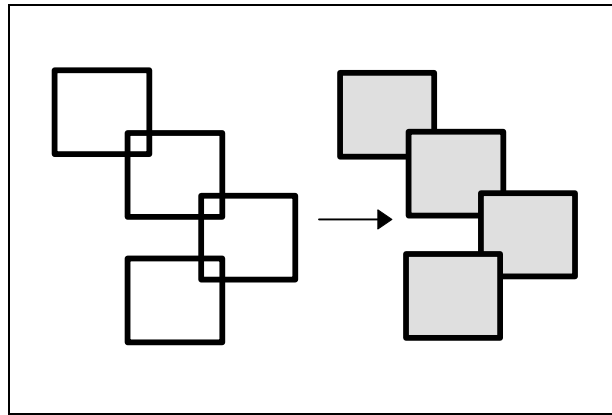


Figure 2. Replacement of the existing system by an alternative system

Two examples provided by Rosenberg (1982), incandescent lighting and hi-fi systems, nicely illustrate the distinction between system replacement and component replacement. Incandescent lighting consisted of four key technologies: the generation of electricity at a central power station, a conductor network for the transmission of power, a meter to measure household consumption of electricity, and a lamp. What distinguished successful inventors-innovators in incandescent lighting, such as Thomas Edison and George Westinghouse, was that they “consciously thought in terms of the entire system, the purpose of which was to deliver cheap illumination into millions of domestic residencies” (Rosenberg, 1982, p.60). As a consequence, both Edison and Westinghouse made major contributions in each of the interrelated technologies making up the system. More typically, Rosenberg notes in his discussion of the hi-fi system, one would expect the various component elements of the system to be produced by different, specialist suppliers. This distributed production immediately raises the co-ordination problems associated with collective innovation discussed previously.

Recent hi-fi history provides a nice example of component replacement. The hi-fi system contains both a ‘chain’ of hardware components (usually a CD player, an amplifier, speakers, tape recorder and a perhaps a tuner), and software (CDs and tapes). First introduced in the early 1980s, CD players managed to replace the LP turntable as the primary input source of the hi-fi chain within just a decade. Despite some early discussions concerning the development of a purely digital hi-fi system, and some experimentation in amplifiers containing built-in DACs, the replacement of LP by CD did not lead to technological imbalances in the hardware chain as a whole. For example, it had no perceptible impact on amplifier or speaker technology, or the standard interfaces and connectors that link the hardware chain together. Indeed, returning to the earlier discussion of interface standards, CD player manufacturers took full advantage of a common, pre-existing interface standard by which to connect line-level input sources to amplifiers. By conforming to this common interface standard, CD players were readily accommodated into the hi-fi chain without users needing to upgrade or alter their existing amplifiers.

Herein lies an important difference between the systems account given by the complex technology model and the single product account that is typically offered. On the single product level, the introduction of the CD appears to be a radical innovation. It is based on a set of technological principles (a combination of laser and digital conversion technologies) which are very different to LP player. A lock-in account, for example, would take this radicalness as given and then seek to explain how one particular variant of this radical new technology became the single 'dominant design'. However, from a systems perspective, the development of the CD was successful in part because changes were made at the sub-component level while leaving alone the other technologies and artefacts that make up a well-established hardware system. Furthermore, the switch to CD did not lead to a radical shake-up in the music industry. Neither did it effect the power bases of the large software providers nor the distribution networks that deliver software to the end-user. True, the fortunes of LP turntable manufacturers were affected, a few of which disappeared because they did not make the transition to CD quickly enough. However many did successfully switch to CD player production and some (such as Linn) have even successfully diversified into the production of speakers and amplifiers in addition to CD players.

A key aspect of complex technology systems, which still needs to be discussed, is the underpinning conceptual frame (or 'gestalt') that defines a system. Here an important parallel can be made with Thomas Kuhn's work on the nature of scientific revolutions (Kuhn, 1962). According to Kuhn a defining aspect of a scientific revolution is a gestalt shift which leads one to see the world in a radically new way. While some theorems of the previous scientific paradigm may be retained, these are understood and viewed in a completely different way by the new scientific paradigm. Similarly, a defining aspect of a technological succession is the replacement of one conceptual frame with another. The incandescent lighting case provides a very clear case of system succession because every element of the system was a new and novel technological innovation. However a new system may also make use of a limited number of pre-existing technologies. As in the case of a scientific revolution, a component element of the new technology system may have originally belonged to an earlier technological incumbent, although this element will be taken up and used in a different way by the new system.

The final distinguishing feature of the of the succession model its consideration of multi-agent selection environments. In addition to the selections made by economic actors (i.e. consumers and firms), the model consider how selections made by a range of relevant actors, including political and other interest groups, shape the evolution of a complex technology. Rip¹⁰ highlights three relevant dimensions; the business environment (dominated by market relationships with customers and suppliers), the regulation environment (government and other regulatory bodies) and the wider societal environment (consumer organisations, environmental groups, the media, public opinion leaders and independent scientists). A product is a device that mediates between the interests of these different agents. One cannot understand the emergence and use of a technology, Rip argues, without an explicit examination of the way in which the (possibly conflicting) interests of multiple agents interact through a product. Furthermore, it is the very act of mediation that leads to qualitative change in a product's form over time.

¹⁰ Rip (1992), Deuten, Rip and Jelsma (1997), and Rip and Kemp (1998).

Extending the analysis in this way additionally allows one to consider both market and quasi-market niches, and the relationship between the two. Innovation rarely, if ever, involves the sudden appearance of a 'ready made' device which then diffuses in an unchanged form over time. Rather, it is a drawn out process in which modifications are made to a technology over a long period of time. The technology may therefore go through numerous transformations and incarnations prior to the 'appearance' of a commercial product that can successfully challenge the dominant position of an established incumbent. Furthermore, Rosenberg and Frischak observe that even when these new products enter the market, "Their performance is usually poor, compared to existing (alternative) technologies as well as to their future performance" (Rosenberg and Frischak, 1983, p.147). Herein lies an opportunity for governments to support new technologies that it perceives as promising alternatives. Such intervention can occur at the competitive or pre-competitive stage. The post-war era is replete with examples of basic technologies - such as lasers, nuclear physics, genetics and biochemistry, aeronautics, electronics and geodesy - that were supported in their formative (pre-competitive) stage through state funding, either in military R&D labs or else in applied scientific research. In effect, national governments have used their financial and legislative power to establish quasi-market niches for new technologies that are in their pre-competitive stages. As we shall see, this was an important aspect of the Internet story, as was the way in which national governments (particularly the US) chose to 'privatise' the Internet. It is to this, and to other aspects of the Internet, that we next turn.

5. *A second account of the Browser Wars*

Let us consider an alternative account of the Browser Wars based on the complex systems perspective. We begin by observing that the Browser Wars were, in fact, one aspect of a 'bigger picture'; a picture in which a system based on the concept of e-commerce is seeking to replace the traditional forms of production, distribution and consumption. The Internet is a key component of this new system because it is the principle means by which distributed computing network can be organised that integrates what have, until now, been a series of localised (semi-) automated computing processes. As the same time it offers the possibility to automate and integrate other processes under one roof. The web browser is the most popular user interface for the Internet. It is this, rather than the economic rents associated with browser production, that makes the browser strategically important because it provides commercial leverage over the Internet and, hence, e-commerce.

The words 'Web' and 'Internet' are often used interchangeably in the popular media. However the two are not identical. The Web is one particular application of the Internet. In addition to Web traffic, the Internet carries a significant amount of e-mail, newsgroup and FTP data traffic. The word 'Internet' is an abbreviation for 'internetwork' or 'network of networks'. A key defining feature of the Internet is the series of communication protocols that enable local area networks (LANs) and wide area networks (WANs) to be linked together. In addition to the

computer hardware and software bundles that constitute the nodes of the network¹¹, there is a set of protocols that facilitates communication between these nodes. Three related protocols make up the TCP/IP standard; the Internet protocol (IP) that specifies what all packets should look like, the routing information protocol (RIP) that is used by routers to discover what is connected to the Internet and the direction packets need to take in order to reach their destination, and the transmission control protocol (TCP) that allows large blocks of information to be broken up into flows of small sequence-numbered packets. The World-Wide Web is essentially a means of transferring documents over the Internet. The Web has a distinct, and separate, set of communication protocols that govern the finding, retrieving and reading of documents. Uniform resource locators (URLs), such as <http://www.company.com/dir/file>, are a standard way of specifying a type of web document, the DNS¹² name of the server where it is to be found, and the location of the document on the server's disk. Hypertext mark-up language (HTML) is a standard format for web documents that allows them to be formatted richly and to make references (hyperlinks using URLs) to other web documents, while hypertext transfer protocol (HTTP) uses DNS to resolve URLs and uses TCP/IP to download HTML documents from servers to client browsing software.

Two exemplars have forced the business and financial communities to take e-commerce seriously; Amazon and Dell Computer Corp. Each company has applied e-commerce in similar fashion. Accessing the company's website, the customer selects the product that (s)he wishes to order. At the end of the order the customer initiates an automated payment transactions by providing his/her credit card details. In the case of Dell the customer can actually specify his or her own personalised product package. The software programme handling the order is semi-intelligent, in that it assesses the preferred 'product mix' and tries to dissuade the customer from choosing an unsuitable combination. This information is then taken and the product assembled. This eliminates the need to hold stocks. It is estimated that, if Dell's savings on inventories were replicated across all firms in the US, there would be an annual saving of \$1 trillion per year (James Duffy, CEO of Benchmarking Partners quoted in Fortune, April 1999, p.79). Both Amazon and Dell bypass the need to maintain retail and distribution chains because their products are shipped directly to the end-user by express post. The result is a significant cut in costs, the benefits of which are passed on to the consumer in terms of lower prices.

Ongoing developments in e-commerce imply a business model that goes way beyond the one currently employed by Amazon and Dell. The 'promise' of e-commerce is that every facet of business - from procurement, to billing, to human resources, to customer support - will be integrated within one system, fundamentally changing how consumers, small businesses and major corporations interact commercially. In addition to the new system elements that are the Web and the Internet, e-commerce will integrate and further develop a variety of ICT technologies, such as secure electronic transactions (SETs) and electronic data interchange

¹¹ There are three kinds of computers on the Internet. First, there are client computers of end-users, typically PCs. Second, there are server computers which print, file, mail, process, retrieve, and do various other jobs for clients. Third, there are router computers which move digital data packets around the world among clients and servers. Routers talk with one another to find out who is connected to the Internet and how best to get there.

¹² Domain name system (DNS) protocols are used by name servers to update the easy-to-remember names of networks and computers, and to resolve those names into current addresses.

(EDI)¹³. E-commerce also takes advantage of the new modes of production that have been developed in manufacturing throughout the 1980s and 1990s, such as flexible just-in-time delivery and lean production methods. The socio-economic implications of e-commerce are immense. Indeed, if the aspirations of its proponents are realised, e-commerce will invoke a major socio-economic discontinuity of the kind discussed by Schumpeter (section 4 above) with new assemblages of products and production processes, knowledge bases, and power structures seeking to replace the established order. E-commerce is likely to produce a major shake-up in a number of industries, not least the computer industry, where the likes of Microsoft and Intel have built their commercial empires on the stand-alone PC (or 'WinTel standard'). As Bill Gates made clear in his Pearl Harbour Speech, the very notion of network computing directly challenges the concept of local, 'personal' computing. If Microsoft is to survive the next technological revolution in computing then it must quickly adapt to the new environment.

By exploiting the advantages of parallel processing, the computational power of the Network Computer or 'NC' is far superior to the stand-alone PC (Tchuente, 1991). Indeed much of the processing power of a stand-alone PC lies idle in practice. Linking together a set of PCs within a distributed network system frees up this latent processing power. At the same time it removes the need for expensive stand-alone PCs on every desk. By exploiting the distributed processing power of the network, PCs can be replaced by cheap terminals for basic data entry and word processing tasks. This is because programme modules can be downloaded and run anywhere on a network. The potential savings for an organisation with even a modest complement number of computers can be significant. Other significant advantages are to be had by using one common cross-platform operating system, such as Java. A common, cross-platform operating system enables a user to run the same software on all machines linked to the network, regardless of whether they are UNIX, PC or Mac-based.

There are two rival power axes in network computing. On the one side stands the AOL/Netscape-Sun-Oracle alliance, on the other stands Microsoft and its allies. The threat posed to Microsoft is far greater and broader than the control of a graphical interface for the Internet. To the original Netscape-Sun-Oracle alliance, established in 1995, Netscape bought its newly-acquired control of Web standards, Oracle its software expertise, and Sun its Java operating system. At the same time Sun would develop cheap workstations, such as Sun's Javastation NC for basic data entry tasks. The subsequent take-over of Netscape by AOL has, in a very important sense, strengthened the original troika. AOL was already the largest portal on the Web¹⁴ with 14 million subscribers, most of whom are consumers. To this it added Netscape's Netcenter portal, which has 9 million registered users, a large proportion of which are corporate registrations. AOL had previously acquired CompuServe Inc., which attracts small business users. The Netscape deal now means AOL captures 60% of all Internet subscribers, giving it an unprecedented opportunity to bring together consumers and businesses within the same 'virtual' space and significantly raise the volume of electronic transactions.

¹³ EDI is the computerised inter-firm communication of trade documents in a standard format that permits the automatic handling of transactions (Sokol, 1989).

¹⁴ A portal is a heavily trafficked website through which people pass either to look for information, or else to buy and sell goods.

The Navigator-IE Browser War must be set against this broader context. Microsoft may have successfully captured the browser market, but it has by no means seen off the AOL/Netscape-Sun-Oracle NC challenge. In fact one of the main problems faced by Microsoft is the need to operate on so many different fronts at once¹⁵. For example, Microsoft has engaged itself, with varying degrees of success, in developing large-scale servers and workstations to rival Sun's hardware offerings. Together with Intel, it has developed two rival products to the NC terminal; the Network PC, which meets many of the criticisms levelled at the PC without discarding Windows, and a cheap Windows Terminal that can be used for data entry and other basic tasks. Intel has at the same time been working closely with a group of hardware manufacturers to develop a sub-\$1,000 Pentium PC. Another key area in which Microsoft is engaged is the supply of 'broadband' digital services, the so-called 'Internet 2', that combines voice telephony, television, and rapid (and continuous) Internet access. Here the company has entered into a whole series of strategic alliances and stock market acquisitions. These include a \$57bn joint bid with AT&T for MediaOne, the US cable television company that additionally involves Microsoft taking a \$5bn stake in AT&T. Through this deal Microsoft aims to build a strong position in adapting cable networks to Internet technology (Financial Times, 7th May 1999).

It is as yet unclear whether these forays will prove successful. However it *is* clear that Microsoft has been singularly unsuccessful in meeting the NC challenge in other areas – notably in its attempts to undermine Java and in its dealings with AOL. AOL has outmanoeuvred Microsoft in the battle to become the leading Internet portal. A particularly crucial error on Microsoft's part was the exclusivity deal struck between Microsoft and AOL in early 1996. At that time Microsoft had the opportunity to unseat AOL as the leading online services provider. However, rather than pushing on with the development of Microsoft Network, its attention was focussed on Netscape and the browser market. Microsoft struck a five year deal with AOL whereby, in return for IE being the sole default browser on AOL, it agreed to exclusively feature AOL's online service on millions of copies of Windows. AOL's subsequent acquisitions of CompuServe and Netscape, and its strategic alliance with Sun, has transformed AOL from being a large retail ISP to perhaps Microsoft's most dangerous rival. Microsoft has been equally unsuccessful in its attempts to see off the challenge of Java to its own Windows/IE as the standard operating system for network computing. Microsoft signed up as a Java licensee shortly after the release of Java 1.0. The licence covered the development of software tools and browser applications. However Microsoft sought to undermine the universality of the Java VM by propagating its own version of the basic language and by developing its own proprietary extensions (known as ActiveX) of the VM standard. This result was that programmes written in the Microsoft version of Java were incompatible with the original Sun standard. At a stroke this undermined the whole point of Java, which is to enable programmers to write software that can be run on *any* computer platform. Sun's reaction was swift. On 7th October 1997 it sued Microsoft for a violating its licensing agreement. Judge Ronald M. Whyte ruled in favour of Sun on 17th November 1997, ordering Microsoft to ship Sun's version of Java within 90 days. While Microsoft did not have to recall software already shipped with its modifications, it henceforth had to include the official Sun Java

¹⁵ There is speculation that Microsoft will undergo a major organisational restructuring, ahead of any ruling arising from the DoJ anti-trust case. This could involve the corporation dividing itself into a number of small units, each relating to a different part of e-commerce. If true, this indicates that Microsoft is far more worried about the its ability to cope with the rapidly changing marketplace than by the US authorities.

in the Microsoft's Windows VM and Visual J++ software development tools (Guardian, 2nd April 1998). Microsoft has thus been singularly unsuccessful in its attempt to see off this very real threat to its Windows operating system.

Analytically, the foregoing discussion highlights the problems that can arise when the focus is too restricted. The attempt to reduce the discussion to a single product, the web browser, is highly misleading. Success in the browser arena is far from sufficient to guarantee overall victory. Indeed, as much as Microsoft has been successful in ensuring IE is the *de facto* browser standard, it has been equally unsuccessful in the other key areas of this much broader conflict. In contrast to the lock-in model, the complex systems model discussed in section 4 places great emphasis on the wider context of technological competition, not only in terms of the systemic relationships between technology artefacts but also in terms of the various actors - scientific, political and military as well as commercial firms - that shape technological change. Indeed this broad constituent of actors has left an indelible mark on the Internet, both in terms of its character and the standards that are being fought. Picking up on two points regarding technological innovation made in section 4, the Internet did not spring, fully-formed, from the mind of a single 'great inventor'. It is the collective product of a whole series of contributors and has undergone a whole series of transformations to its appearance as a technology of commercial relevance. Second, a variety of publicly-funded institutions have played their role in this development. What is more, the manner by which the Internet was privatised has had immense bearing on the HTML and Java standards battles discussed above.

It is possible to delineate three phases in the Internet's history. The first was a 'military phase' in which the objective was to develop a computer network robust enough to transmit data, even if one or more nodes were incapacitated by a nuclear strike. Conducted at the peak of the Cold War, this research focused on how wide-area network (WAN) of computers could be kept running, even if one or more nodes became incapacitated through a nuclear strike. This, of course, remains one of the distinguishing features of the modern Internet¹⁶. In 1969 engineers and scientists at the Pentagon's Advanced Research Projects Agency (ARPA) began to develop an experimental WAN that would provide a test-bed for emerging network technologies. The network was named the ARPANET. Four universities were connected to ARPANET in the initial set of trials, enabling scientists to share information and resources. The network was subsequently expanded throughout the 1970s to include universities, a few military labs, and several research laboratories. By the end of the 1970s there were around 100 connected computers.

A second, 'scientific phase' of the Internet commenced in 1983 following the decision of the US authorities to remove the military network sites from the ARPANET by setting up a distinct MILNET network. While it was probably unintentional, this separation proved to be an important stimulus for the development of the Internet. The remaining network of universities and academic research facilities was placed under the National Science Foundation (NSF). In 1985 and 1986 the NSF connected together the USA's six supercomputing centres to form the NSFNET, or NSFNET backbone. Academia now became both the main user of the Internet and

¹⁶ An Internet is a wide-area network (WAN) that is composed of many local area networks (LANs).

its main source of innovation. In order to expand access, NSF supported the development of regional networks which were then hooked up to the NSFNET backbone. In this way NSFNET was able to connect regional, national and international nets. In addition, the NSF supported universities and other public research facilities to use the NSFNET for file exchange and communication. A mark of the programme's success was a rapid increase in the number linked computers. In 1983 there were 562 computers linked to the Internet. By the end of the decade the number had increased to over 100,000. This expansion was greatly facilitated by the adoption of TCP/IP as the standard set of networking protocols in 1983. This represented a major breakthrough in network computing because, prior to TCP/IP, it had been very difficult (if not impossible) to get the network software developed by rival commercial companies to communicate with each other. The decision to use TCP/IP marked an early commitment to the development of open, non-proprietary systems as the basis on which the Internet was to be built.

Around this time CERN in Europe and several US physics laboratories started to use the Internet as their primary means of exchanging test data and documents. The high energy physics community is small but widely spread throughout the world. The physics research laboratories of the world frequently collaborate, and the exchange of data and documents is a primary activity. Such an environment provided fertile ground for a system that facilitates communication over networks. The adoption of the Internet by CERN and the leading US laboratories was therefore an important factor in its becoming the standard academic network. There were plenty of protocols for network communications available but a major problem was how to find, retrieve and read information from the Internet. The stage was thus set for Tim Berners-Lee and the World-Wide Web. Towards the end of 1989 Berners-Lee proposed a networked hypertext system for CERN. Coincidentally, Robert Cailliau had proposed a hypertext project for documentation handling inside the CERN laboratory. The two joined forces and in 1990 presented a refined joint proposal for a hypertext system. By the end of that year the prototype software for a basic system was being demonstrated. The prototype system included the WWW browser, an information server and a library implementing the essential functions for developers to build their own software. This was released in 1991 to the high energy physics community via the CERN programme library, enabling a whole range of universities and research laboratories to access it. A little later it was made publicly available over the Internet.

Although Berners-Lee's prototype was very sophisticated, it was only available for NeXT machines, which were not widely used. Consequently a stripped-down version (with no editing facilities) was constructed. Christened the 'Portable Line-Mode Browser', it was multi-platform but was limited in power and not very user-friendly. It soon became clear that the existing browser technology was placing a limitation on the diffusion and growth of the Web. Moreover the small research team at CERN was unable to undertake the work needed to develop the system further. Consequently Berners-Lee launched a plea via the Internet for other developers to join in. His call was answered by the release of the first version of the Mosaic browser by NCSA. Mosaic overcame the weaknesses of the early browsers developed at CERN. As well as offering a user-friendly interface, it could be run on standard UNIX, Macintosh and PC platforms¹⁷. In

¹⁷ The first publicly released version of Mosaic was for UNIX machines running X-Windows (popular within the academic community at that time) in January 1993. In August 1993 NCSA released versions for the Mac and the PC.

addition, the software allowed in-line colour images, making it the first popular graphical web browser. Mosaic could be downloaded for free by individuals and companies wishing to use the (academic) Internet. It was also licensed to IBM, Microsoft and other computer companies through a spin-off company called Spyglass Inc. As well as earning rents that could be put back into research, it would enable NCSA to maintain control over the open HTML standard. The NCSA browser standard represented a final piece in a jigsaw of complimentary and *publicly funded* set of standards that underpinned the World-Wide Web: the NCSA-HTML-TCP/IP standards. The existence of reliable, user-friendly browsers on the PC and other popular computers had an immediate impact. Usage of the Internet literally exploded following the release of Mosaic.

The rapid growth of the Internet in the early 1990s, and the realisation of its commercial potential, brought with it an increased pressure for ‘commercialisation’. Indeed the subsequent unfolding of the Browser Wars was fundamentally effected by the manner in which the Internet was privatised. Because they were funded by the US government, ARPANET and NSFNET had originally excluded commercial traffic from these networks. However, the commercial potential of the Internet, as a tool for business communication, was increasingly recognised by the late 1980s. Several private networks handling commercial traffic, including CompuServe and BITNET, began to spring up. However NSF policies meant these were unable to communicate with computers on the NSFNET backbone. The situation was not helped by the fact that many commercial providers did not support TCP/IP protocols and so were incompatible with the NSFNET. This was solved in 1988 when gateways were placed between NSFNET and commercial networks carrying e-mail, enabling a CompuServe or BITNET user to communicate with an NSFNET user and vice versa. As commercial traffic continued to expand, the US government shifted its position and moves toward the privatisation of the Internet began in earnest in the mid-1990s. On April 30th 1995, the NSFNET was converted into a number of commercial sites. The administrative powers of the NSF had by this time been transferred to a new body called the InterNIC, which henceforth provided network addresses and other basic support services¹⁸. No longer responsible for backbone provision or management, the NSF was left to provide Network Access Points (NAPs) that facilitate the interconnection of multiple, private Internet Service Providers (ISPs) who serve their own end-users. In addition to the privatisation of NSFNET, there was an important shift in the position of both US and European authorities towards open (common) standards. Whereas the authorities had encouraged and safeguarded the development of a common set of standards in its pre-competitive phases, the free market ideology of the US and many European governments of the time, dictated that they should stand aside and allow the private sector to structure a commercial market. If this required companies such as Netscape and Microsoft making the HTML standard proprietary, then so be it.

The lock-in account of section 2 sought to explain Netscape’s victory in the first Browser War through the technological superiority of its browser. However this was only one aspect of the story. Equally important was the manner by which Netscape added its own extensions to the

¹⁸ In Europe and surrounding areas, these activities are performed by the RIPE Network Coordination Centre. The RIPE NCC acts as the Regional Internet Registry (RIR) for Europe and surrounding areas. The IANA allocates blocks of IP address space to Regional Internet Registries. RIPE NCC allocates blocks of IP address space to its Local Internet Registries (LIRs), who assign the addresses to end-users.

(open) NCSA-HTML standard in order to create its own proprietary version of HTML. This strategic use of standards is highlighted by Newman in his article 'How Netscape stole the Web' (Newman, 1997). Rather than focusing on the design team led by Marc Andreessen, Newman highlights Jim Clark's role in the first Browser War. Clark was a CEO at Silicon Graphics at the time of Mosaic's release. A veteran of the UNIX standard wars, he understood the commercial power associated with the proprietary control of a platform standard. At first the Netscape extensions consisted of new text formatting options. Later it added Frames, coloured backgrounds and many other non-standard features. At the same time Netscape brought other commercial developers on board by allowing third-party 'plug-ins' to their browser architecture. In this way other firms not only supported the Netscape browser but added further functionality and features not present on the NCSA browser. The first pug-in for Navigator 1.0 was the highly successful Adobe Acrobat programme. By the time Netscape 4.0 was released 154 third-party plug-ins were available.

The purposeful differentiation of HTML code between the Netscape and NCSA browsers meant that Web pages designed to work with Navigator could not be read by Mosaic users. By giving away its browser, getting other software developers on board, and by building up a large user base, Netscape was able to charge designers for the server software needed to develop pages with its proprietary extensions. As Newman notes, this marked the first successful attempt by a commercial company to take over the standards creation process of the Internet. The University of Illinois, quite naturally, complained. It accused Netscape of dumping and avoiding licence payments on Mosaic. Yet, despite the fact that the US government had funded and backed the standards developed by NCSA, it did not act to oppose Netscape. There were no investigations into unfair trading or an announcement that the US government would only use NCSA-approved codes on government websites. The silence from the EU, which had financed and backed the standards developed at CERN, was equally deafening. Given this general lack of support, the University of Illinois quickly threw in the towel and signed an exemption agreement with Clark in December 1994.

If national governments adopted a hands-off approach to standards issues in this period, what role was taken by the industry's own standards bodies? The principal Web standards body is the World-Wide Web Consortium (the W3C). Its agenda was set by first and second International World-Wide Web Conference (held, respectively, at CERN and Chicago in May and October 1994). Together these conferences set out a clear agenda for the future development of the Web. To succeed, the technology had to be continually extended to cater for new needs. Security, authoring, multimedia, and access by session and billing were highlighted as important features requiring immediate action. At the same time it was agreed that all new Web developments should be common standards, open for all to use and not locked up in proprietary ownership. This objective became the *raison d'être* of the W3C, when it was formed shortly after by Tim Berners-Lee. In practice the W3C has been a rather ineffective regulator. It has certainly failed to prevent Netscape and Microsoft from developing proprietary versions of HTML. Complaints about the slowness of its procedures are also common. Rather than setting the agenda, critics complain, the W3C is busy trying to keep up with changes driven by the main corporate players. This leads to the charge that, while the W3C appears highly democratic on the surface, its agenda is set by large corporate interests. Certainly this is the charge made by Netscape, who have accused the W3C of rubber stamping Microsoft's proposals for XML and a number of other

standards. In response, Netscape has refused to adhere to these W3C-supported standards.

This brings us to the relationship between common (open) standards and private (proprietary) standards, and the strategic choice between co-operating on an open standard or developing one's own proprietary standard. Addressing this issue bridges the discussion of product competition with the wider standards setting process. Leading players such as Netscape and Microsoft are strategically choosing whether to play an open or proprietary standards card. At times they are willing to support the development of standards through bodies such as the W3C and the IETF (to which they are both members). At other times they deliberately undermine the standards that give an advantage to the opposition. There are those who are inclined to cast Microsoft as the villain. However, as the earlier discussion makes clear, both sides have been playing the same game. Netscape's Jim Clark raised a particularly important point on the conditions necessary to maintain an open public standard;

"At some level, standards certainly play a role, but the real issue is whether there is a set of people, a set of very powerful companies, out there who don't play the standards game. For the standards game to work, everyone has to play it, everyone has to acknowledge it's a game. Companies such as Microsoft aren't going to sit around and wait for some standards body to tell them 'You can do this'. If your philosophy is to adhere to the standards, the guy who just does the de facto thing that serves the market need instantly has got an advantage." (Jim Clark, quoted by Newman, 1997).

The strategies played by Netscape and Microsoft have been particularly intricate. What factors have influenced the decision to develop an open or proprietary standard? Does the rate of innovation depend on a balance being struck between open and proprietary standards and, if so, what is this balance? There has been a vigorous debate in the standards literature regarding the relative merits of different approaches to standard setting; in particular, whether the interests of users and producers are best served by *de jure* standards set by institutions or consortia, or by *de facto* standards that emerge after a process of competition. Recent empirical research conducted by Windrum (1998) also highlights the open-proprietary distinction but suggests there is no 'rule' that states that one form of standard is universally preferable to another. Indeed interviews with web authoring companies, freelance designers and their clients suggest that a balance needs to be struck between the two. On the one hand, the commercial development of the Internet means there must be a development of proprietary application software and services that generate economic rents for their inventors. Within this domain, it is widely agreed that competition between rival proprietary alternatives is important for pushing Internet technology forward. On the other hand it is argued, equally strongly, that the common platform of communications protocols, core languages and UNIX-based operating systems that underpin the Internet must remain open, common property. There is a widely shared belief in the Internet community that collective invention through open source software is a major driver of innovation. This innovative driver breaks down when one company gains proprietary control of a core standard. Ensuring the set of underpinning standards remains open property is therefore the best means of guaranteeing freedom of competition between the applications built on the core standards. This view of the relationship between open and proprietary standards recasts, in a far more subtle form, the argument that the end user is best served when innovation is driven by product

competition that is based on set of open standards.

Of course commercial firms *will* seek to capture an underpinning standard if this confers a competitive advantage. The discussion of the HTML standard provides a clear example of how competition between rival commercial applications can quickly spill over into a battle for an underpinning (previously open) standard. The economic incentives can be such that commercial companies, from the outset, seek to develop a core standard that they can hold under tight proprietary control. The software industry has learnt many lessons from Microsoft's control of the Windows operating system. Sun is similarly intent on using Java as a means to establish a dominant position within network computing and has, at each stage, been careful to keep Java under tight proprietary control. On other occasions firms choose to develop open standards. Indeed, on closer inspection, it becomes clear that both Microsoft and Netscape have played a *dual strategy* in the Browser Wars; sometimes co-operating in the development of open standards, at other times competing with each other in proprietary standards battles. The choice of which strategy to play depends on the circumstances faced by the firm. Two conditions were highlighted in the Windrum (1998) study as essential for the development of open standards. The first is a high degree of market uncertainty. The second condition is that no company, or coalition of companies, has previously developed a core technology that is capable of becoming a standard. E-commerce provides a number of examples where the rivalries of the two power axes in network computing have been put to one side. There are currently some 200 companies, including the likes of Cisco, Netscape, Microsoft, IBM and HP, involved in the development of e-commerce. Despite waging open war with each other on other fronts, the AOL/Netscape-Sun-Oracle alliance and the rival Microsoft alliance have willingly partnered up in areas such as secure electronic transactions (SETs). Here each side is unsure as to where the market is moving and so is willing to cluster together and co-operate to their mutual benefit. As one interviewee put it, "fear is a key motivating factor - the fear that there is more to lose by not sharing information and being left behind". Therefore firms will collectively develop open standards provided there is a shared common interest in so doing.

A number of policy implications for IPR and the standards setting process follow. There is a widely-held belief amongst those contacted by Windrum (1988) that a relatively relaxed attitude towards IPR, far from inhibiting innovation, has greatly facilitated a rapid development of the Internet. A variety of contributors have been able to use and reuse open resources to develop new ideas and new types of software. Ensuring variety within an 'innovation pool' is viewed as essential for high rates of innovation and technological change. This pool currently ranges from languages and UNIX operating environments on the one hand, to public domain image libraries and website designs on the other. Different organisations and individuals are free to dip into this pool. In turn, through their own innovative activities, they generate new solutions that add to the resource pool which others can in turn draw upon. It is widely recognised that IPR issues will become increasingly important as e-commerce continues to develop. The commercialisation of the Internet requires the development of proprietary applications that generate economic rents for their inventors. However it is equally stressed that a clear distinction needs to be drawn between the core platform of communications protocols, languages and UNIX-based operating systems that underpin the Internet, and the proprietary products that are built on these core standards. This distinction needs to be institutionalised if repetition of the anti-competitive practices witnessed in the PC market is to be avoided.

This is the central issue behind the ongoing the DoJ courtcase against Microsoft. The political stance towards the Internet in the US has changed once more, with a move away from the laissez faire position of the previous Republican administration. The change is not simply prompted by a change in political administration, although this is clearly a factor. There is also a realisation that an unfettered market may not guarantee innovation and choice on the 'information superhighway'. President Clinton has highlighted the importance he personally attaches to the DoJ courtcase against Microsoft. In his view the control of the information superhighway is at stake. "This is not just an open and shut case of one party suing another. This is something that could have a significant impact on our economy" (Daily Telegraph, 19th May, 1998). The Clinton-Gore vision of the information superhighway is certainly very different to Bill Gates'. The Clinton-Gore vision is of a technology that empowers people, in much the same way as early 20th century US presidents viewed the car as an empowering tool that would draw together the 48 (as it was then) disparate states of the union, make it easier to farm the untamed prairies and draw rural American closer to the big cities. So the Clinton-Gore vision is an explicitly populist one in which the telecommunications revolution will connect the US for a new century, raising educational standards and rescuing the poor from the inner cities (Guardian, 21st May 1998). Bill Gates' vision could not be more different. At the centre of his vision are the interests of Microsoft. There is an implicit assumption that Microsoft's interests and the public good are one and the same. The computer technology revolution has helped revitalise a US which, in the early 1980s, appeared stuck with a rustbelt economy of steel, automobiles and chemicals, while the Japanese had seized control of the sunrise electronic industries. The downside of Gates' vision is a lack of choice. Worse, US regulators fear that Gates will exploit his power within the computer industry to control access to the Internet or, at the very least, make huge profits from the transactions executed on it.

The notion of promoting competition and innovation through the protection of common property marks a radical departure from established IPR policy. The existing regime seeks to stimulate individual innovation by providing legal IPR mechanisms that guarantee (temporary) monopolistic rents. At the same time it seeks to curb anti-competitive practices, either by controlling mergers and acquisitions (the European model) or else through anti-trust actions (the US model). The proposed policy shift involves an alternative standards framework with new institutions capable of taking collective, as well as individual, benefit into account. One possibility is a standards institution with legal powers to adjudicate on standards issues. In addition to protecting a core set of open e-commerce standards, such a body would protect small firms against IPR infringement. Evidence from the software industry indicates that small companies are disadvantaged under the current system because they do not have the financial resources to take larger companies to court over IPR infringement – the only form of redress which is currently available to them. A more effective threat is the release of information that would sully the reputation of the offender within the industry. By tapping into existing community norms and ethics, a more flexible and more effective means of protecting small firms against plagiarism could lie in giving a standards body the power to publicly adjudicate over certain types of IP disputes. The success, and public acceptance, of the proposed regime depends on two factors: its breadth of scope and its democratic credentials. Consequently, it is essential that such institutes have a wide representation that draws from all the relevant interest groups. For example, in addition to representation from various producer groups there must be representation

from interested consumer groups and similar organisations. What is more, given the explicitly international context of the Internet, there must also be judicial and political representation within these institutions. Institutions comprising expert practitioners would not only extend the scope of decision-making but also increase flexibility and speed up adjudication, while retaining the option for further judicial process when required.

6. *Conclusions*

The paper has considered two alternative models of technological competition and examined their ability to capture key stylised facts about the Browser Wars. A number of problems were identified in the lock-in account. First, there are two levels at which technological competition occurs. In addition to competition between rival variants of a new technology, there are battles for technological succession in which new technologies seek to displace established incumbents. Unfortunately the tools provided by the lock-in model do not facilitate an examination of this latter type of competition. Second, the lock-in model also has problems in dealing with key aspects of the variant battle fought between Netscape and Microsoft. Despite its now almost universal application, the model was originally intended to describe technological competitions between contemporaneous and unsponsored variants that begin with roughly equal market shares. It was not designed to discuss the strategies used by a late entrant to overcome the first-mover advantages enjoyed by a pioneer. It is hardly surprising, therefore, that the model exhibits difficulties when applied to empirical cases, such as the Netscape-Microsoft battle, where one variant has a monopolistic market share at time t_0 . The paper discussed how the basic lock-in model could be adapted in order to deal with the problematic features of the Netscape-Microsoft case, but a question mark was placed against this ad hoc approach.

The paper then considered a second account based on the model of technological succession. It argued that this alternative model is better suited to the Browser Wars discussion because it incorporates four key aspects of the study that are excluded by the lock-in model. First, the principal research question of the succession model is how e-commerce, of which the Internet represents a core component, is seeking to unseat established methods of production, distribution and consumption. A second distinguishing feature of the succession model is its systems focus. It examines complex technologies that comprise a number of interrelated products. Under this perspective the web browser is one element of a new technology system and must be analysed within its broader system context. This system perspective gives rise to a third distinguishing feature; a discussion of the conceptual frames (gestalts) that define rival systems and the mechanisms that help link the elements of a system together. The latter highlights the link between which product competition and the wider standards setting process. This is particularly important in the Browser Wars, where the ability of Netscape to capture and make proprietary the (previously open) NCSA-HTML standard was a key aspect of its victory in the first Browser War. It was a policy that Microsoft similarly pursued in the second Browser War. Indeed the analysis indicated that both Microsoft and Netscape have played a dual strategy; sometimes co-operating in the development of open standards, at other times competing with each other in proprietary standards battles. Finally, the succession model considers a range of actors whose

enrolment has a bearing on the outcome of this technological competition. In addition to Netscape and Microsoft, this includes other members of the Internet community, such as ISPs, third-party providers and industry standards bodies like the 3WC. Actors from outside the Internet community have also played an important role in its evolution. The paper highlighted the important role played by a variety of publicly funded institutions during the first two phases of the Internet's history. It also suggests that government an important role in the current phase of the Internet. If, as the standards literature argues, the end-user is best served by product competition based on common set of open standards, then a new regulatory framework is required in which private interests are balanced by the public interest.

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