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Leveraging technological externalities in complex technologies: Microsoft's exploitation of standards in the browser wars

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Abstract

Netscape enjoyed a 90% installed user base for its Navigator browser in August 1995 while the market share for Microsoft's inferior quality browser was negligible. By August 1999, Microsoft had captured 76% of the browser market. Extant theory has focused on late entrants' ability to win standards competitions through the development of products with superior quality/price performance. Yet this does not explain Microsoft's success. Microsoft succeeded by leveraging installed user bases across vertically related markets, from Windows to IE. To date, little or no attention has been paid to the leveraging installed user bases. This paper addresses this by developing an analytical framework, based on a coupled Polya Urn model, that captures the dynamics of the Netscape–Microsoft battle. The framework highlights the strategic potency of controlling a proprietary standard in a vertically related market.

Keywords: Standards; Polya Urn; Lock-in; Web browser; Microsoft

1. Introduction

The web browser is a well-defined technological artefact that is used to communicate over the internet with web servers using HyperText Transfer Protocol (HTTP). When a user first opens his/her browser, the browser follows a link that reads a document written in HTML/XML and displays this in a window. To access a document, the browser uses the HTTP protocol to send a network request for this file to the web server where the document resides. The Web server then responds to the browser's request and, by following the HTTP protocol, sends the requested document to the browser. The browser then interprets the HTML in the document and displays it on the computer screen. Clearly, the web browser is not a stand-alone product. Rather, it is one of a number of complementary components that together comprise the internet. These include content (media and services), hardware (cables, routers, servers, PCs), software (operating systems, browsers, and e-mail), communication protocols (WWW and TCP/IP), and design conventions (that provide website ergonomics and functionality to the user). The internet is thus a complex technology comprising numerous interacting components that are produced by a range of providers—both firms and individuals.

Interoperability standards are important for the integration and development of a complex technology

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such as the internet because they enable vertically related providers to co-ordinate the supply and design of complementary goods and services through procedures other than formal collaboration agreements. In addition to common communication protocols and physical interface standards for the internet, process standards for software languages and tools govern the way in which different hardware/software components are produced. In this way, the complex system can be modularised, improvement in the quality of one product achieved without the need to make accommodating changes in the other products with which it interacts. Formal codification and monitoring of some internet standards are given over to government-sponsored institutions such as ISO, BSI and CEN, for others the responsibility lies with industry-led consortia such as the 3WC and the IETF, while some are the proprietary property of individual firms. The competitive advantage afforded by the private control of a standard can be significant. In addition to the revenues generated though charging for its use, considerable market power is derived through the control of product specification (what a product is), minimum attributes (what it does), compatibility (what else it can connect with) and ergonomics (how a user can interface with it). In addition to increasing its market power, the industry is placed on a technological trajectory that is closely tied to the competences and knowledge base of the standard-setter, subsequent incremental innovations by other firms being readily understood and absorbed. Indeed, as the Microsoft case study illustrates, proprietary control of one standard can be exploited in order to win a standards battle in a vertically related product market.

The next section of the paper considers three aspects of the browser wars: the strategies of product quality, pricing, distribution and the cross-leveraging of installed user bases; the extent to which these strategies were exploited by Netscape and Microsoft, and the factors influencing the demand for rival browser products. While the outcome of the first browser war between National Center for Supercomputing Applications (NCSA) and Netscape can be understood by received theory, the outcome of second war between Netscape and Microsoft cannot. To this end, section three develops a coupled Polya Urn model that is capable of explaining the second browser war. The final section summarises the strategic policy lessons that can be drawn from the Netscape–Microsoft war. For the sake of clarity, the paper does not concern itself with the merits of the long anti-trust case brought against Microsoft by the US Department of Justice. This lies outside the scope of the current paper. Having said this, access to detailed documentation on the strategy of a large corporation such as Microsoft is unprecedented, and certainly assists the analysis.

2. The browser wars

There were two distinct struggles for control of the browser standard: the National Center for Supercomputing Applications (NCSA)–Netscape war and the Netscape–Microsoft war. The first multi-platform graphical web browser was Mosaic, developed by the NCSA. Released in 1993, Mosaic offered a user-friendly interface that could run on standard Unix, Macintosh and PC platforms, and facilitated both text and colour images.[1] The NCSA browser was intended to be the final piece in a jigsaw of complementary 'open' (i.e. non-proprietary) set of standards that would underpin the world-wide web (WWW): the NCSA-HTML-TCP/IP standards. NCSA would maintain control over the open HTML standard, licensing Mosaic and using the rents to fund further R&D.

The course of events did not run this way, and, with the benefit of hindsight, one can appreciate why. Although no company has generated significant profits from sales of web browsers, the browser itself is a key component of the complex system that is the internet—it is the key graphical interface that links the PC to the data and services offered over the internet. For this reason there is a strong incentive to gain proprietary control of the browser technology. In addition to making the company with proprietary control a key internet player with significant market power, control of the browser market can be used to leverage advantage in other, vertically related, product markets. This was aim of Netscape's founders, Jim Clark and Marc Andreesen, when they formed the company on 4 April 1994. They anticipated that

[1] 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.

most of Netscape's sales revenue would be generated by server software packages—for which they would charge up to US$ 50,000—rather than through browser royalties (Newman, 1997). However, getting web publishers to pay for server software required a large installed user base. A way of achieving this was to control the browser market.

Conventional theory highlights four ways in which a new technology entrant can overcome the network externalities enjoyed by firms producing a dominant market standard (e.g. see Grindley (1992), Garud and Kumaraswamy (1993), Schnaars (1994) and Majamar and Venktaraman (1998)). First, the new technology variant is superior to the old technology. Second, the new technological variant is more price competitive. Third, the firm that develops the new technology enjoys a distribution advantage over the firm(s) producing the dominant technology. Fourth, the firm exploits advertising to gain competitive advantage. Netscape's success lay in exploiting the first two strategies. Further, it purposely differentiated its product to create a technological source of density dependence, turning the competition into a winner-takes-all standards battle. The first browser war commenced with the release of the beta version of Netscape Navigator 1.0 on 14 October 1994. Netscape 1.0 was superior to Mosaic, both in its technical design and in its ease of use. As well as being able to load graphic images up to 10 times faster than Mosaic (thanks to its innovative 'continuous document streaming' code), Navigator offered the user innovative features such as easy-to-use navigation and new text formatting options that enabled web publishers to produce more attractive documents. In subsequent versions of Navigator, Netscape added frames, coloured backgrounds and numerous other features that are now considered a normal part of web page design. Further, when used in conjunction with Netscape's server software, the company promised security through encryption and server authentication.

The purposeful differentiation of the Netscape browser from its NCSA rival was central to its strategy of gaining proprietary control of the browser standard. Not only did it differentiate its product's ergonomics and functionality, but it also added its own proprietary extensions to the underpinning HTML code. This meant that Mosaic users could not view features written in the Netscape version of HTML. In this way, Netscape deliberately set up a winner-takes-all standards competition between rival substitutes. Those wishing to put material up on the web were faced with a choice. Either they simultaneously adopted the Mosaic and Navigator platforms, and thereby support multiple versions of their websites (an expensive option in both time and resources), or else they could choose to support one or other platform. Herein lay the technological source of density dependence or 'positive feedback'. If Netscape could persuade increasing numbers of users to adopt Navigator then the incentives for independent content providers to optimise their websites for Netscape-only browsers and servers would increase.

The beta release of Navigator 1.1 in March 1995 saw Netscape enrolling other software companies within its differentiation strategy. This it achieved by fostering vertical value relationships between itself and producers of complementary software. By writing to Netscape's new, proprietary Client Application Programming Interface (API), independent developers were free to create third-party applications, or 'plug-ins', that integrated multimedia files with images and text. One of the first, and most successful, third-party plug-ins was Adobe Acrobat. By mid-1995, independent software vendors had already released 60 plug-ins for Navigator, with the focus increasingly on business applications such as document publishing, spreadsheets and computer-aided design. The fact that Netscape's Client API was proprietary meant these popular plug-ins could run with the Mosaic browser. This ensured that only the functionality of its Navigator platform was extended and enhanced by the innovative activities of third-party providers. In addition to developing a higher quality product that exploited the contributions of third-party providers, Netscape adopted a novel pricing policy—the beta test version of Navigator 1.0 was freely available over the internet, and the finished commercial version of 1.0 (released on 15 December) could be downloaded without charge for a 90-day trial basis by corporations, and was completely free for students and educational institutions.[2] In effect, there was a zero pecuniary cost of acquiring the Netscape browser. Netscape's strategy proved highly successful. By the

[2] A charge was only made on those users wishing to receive customer support.

time the company became a publicly quoted company in August 1995, its browser was one of the fastest-growing software products in history with a 90% share of the web browser market and a 70% of Fortune 100 companies.

In sharp contrast to Netscape, Microsoft initially showed little interest in the internet, believing it would remain a minority interest. Its internet explorer (IE) browser had failed to make an impact on the market (DataQuest, 1997; Statmarket, 1999). This was hardly surprising, given that versions 1.0 and 2.0 of its IE browser (released in December 1994 and December 1995, respectively) were licensed versions of NCSA Mosaic and, as such, were inferior in quality to both Navigator 1.0 and 2.0. As well as being slower in 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. As Bill Gates' 'Pearl Harbor' speech on 7 December 1995 recognised, the growth of the internet not only took Microsoft by surprise, it posed a direct threat to its core market: the operating systems market. Netscape had established an alliance with Sun Microsystems, the explicit aim of which was to turn the browser into a 'super' operating system and, thereby, destroy Microsoft's near monopoly in the operating systems market. This was to be achieved by developing a Java-based cross-platform browser that would effectively sit on top of, and take over the standard command functions from, the Windows, Mac and Unix operating systems. Gates' 'Pearl Harbor' speech faced up to this challenge, and signalled the commencement of the second browser war.

The second browser war was short, starting in earnest in August 1996 with the release of IE 3.0, and ending in November 1998 with the purchase of Netscape by AOL. Following Gates' speech, Microsoft reorganised its corporate structure in April 1996, creating an IE division, and threw resources at internal development. The original IE team was just six people. By the release of IE 3.0 this had grown to a team of 100 people with an estimated annual budget of US$ 100 million. While conventional theory helps explain the outcome of the first browser war, it does not assist us in the second browser war. First, the brief of the IE division was to quickly catch up with Netscape. There was not sufficient time to develop a new product. Hence, IE 3.0 brought Microsoft's technology closer to par on basic features by cloning popular Netscape features such as HTML 3.2, Java support and an e-mail reader. IE 3.0 could not be considered a technically superior browser to Netscape 2.0 (Cusumano and Yoffie, 1998; Shapiro and Varian, 1999). Further, the general consensus is that IE 4.0 represented a step backwards due to its poor design and its being overly complicated to use. These problems were not addressed until the release of IE 5.0 in March 1999. IE 5.0 was Microsoft's the first truly competitive browser, but this was released after the browser war had ended. Microsoft's success in the second browser war cannot, therefore, be explained by superior product quality. Equally, it cannot be explained through price differentiation. Microsoft adopted Netscape's pricing strategy of giving away its browser for free,[3] making the companies' product offers indistinguishable in terms of their pecuniary costs.[4]

In addition to emulating Netscape's browser features and pricing strategy, Microsoft started to add its own proprietary extensions to the underpinning HTML code. By ensuring that Netscape and other rival browsers could not view pages written with IE properly, Microsoft introduced a technological source of density dependence that ensured a winner-takes-all competition. Despite being members of the World Wide Web Consortium (W3C), both Netscape and Microsoft would continue to add more proprietary extensions to HTML code to successive versions of IE and Navigator. As evidence presented in the DoJ case has made clear, Microsoft's objective was to exploit its large installed base of Windows/Office users to IE. Before moving on to how Microsoft achieved this, it is worth considering the nature of this density dependence, for the browser case offers an interesting contrast to the well-known QWERTY keyboard case. As David (1985) explains, there can be non-pecuniary as well as pecuniary costs associated with the acquisition and use of competing technology standards. The speed and accuracy of a typist depends on the mechanical interaction between a typist's fingers and the physical layout of a keyboard. Typists invest significant time

[3] Having captured 90% of the browser market, Netscape had started to exploit its dominant market position by charging end-users a flat fee of $5 for its browser software. However, when Microsoft began to gain market share Netscape once again made its browser freely available over the internet.

[4] This precludes a hedonic price analysis of the features offered by the rival browsers.

and effort in order to maximise their typing speed with the QWERTY layout. Understandably, they are loath to subsequently retrain with an alternative keyboard design. These non-pecuniary switching costs, i.e. the time it would take to retrain with an alterative design, are common to all keyboard users.

In the browser case, there was a deliberately engineered technical incompatibility rather than a user-based source of density dependence. Further, there are two distinct types of browser user. The 'general user', by far the largest in number, uses the browser to surf the web, pick up and download information, and (possibly) purchase goods. In contrast to these information consumers, 'web publishers' are information providers who design and maintain websites, put up information, and (in the case of commercial firms) offer goods for sale and support electronic transactions. There were no learning costs associated with switching browsers since IE and Navigator were so similar in features and layout, and both could be freely acquired. There were, however, pecuniary and non-pecuniary costs for web publishers in designing and maintaining multiple versions of their websites, and in purchasing multiple server software (which both Netscape and Microsoft were charging for). Learning the lessons from the first browser war, Microsoft knew that web publishers had a clear incentive to support just one browser but that this was tempered by the need to reach the widest possible audience. Until it was clear which way the vast majority of users, i.e. general users—would go, web publishers would continue to maintain multiple IE and Navigator compliant versions of their websites.

So, how did Microsoft win over the majority of general users to IE in such a short space of time? Two factors were important. First, Microsoft succeeded in coupling the operating system and browser software markets; two markets that had previously been considered separate. Second, it used its influence in the ISP and computer distribution channels. Following the release of IE 3.0, Microsoft its intention to integrate future versions of IE with Windows, its Outlook e-mail software, and its Office software suite. Not only did this powerfully link the browser market with the operating system market in the minds of consumers, it simultaneously made clear Microsoft's intention to be a systems integrator that would manage in-house the cross-product integration and optimisation of IE with its other software. Microsoft was hampered in moving in this direction by the US courts during the browser wars. The simultaneous release of IE 4.0 and Windows95 operating system in October 1997 was to have marked the first step in the development of Active Desktop, which would enable the user's desktop to work like a web page and push channels of information to it.[5] However, the announcement prompted action by the DoJ to prevent integration, first by asking the federal court to hold the company in contempt of a 1995 anti-trust settlement, and subsequently by starting its own procedures against the company in May 1998. Still, Microsoft's strategy was clearly established and was clearly different to Netscape's. With hindsight, Netscape's alliance with Sun to develop Gecko, a cross-platform browser to run on several operating systems, played into Microsoft's hands. First, the alliance with Sun was openly anti-Microsoft and, by implication, against Windows users. Second, rather than focusing on Windows code, Netscape's developers started to write code for a range of Unix and other operating systems that represent a small minority of the operating system market. This opened the way for Microsoft to directly appeal to the installed user base of Windows users, which far outnumbered the number of Navigator users. The browser market and operating system markets were linked, and users faced a clear choice between IE-Windows, on the one hand, and Navigator-Unix on the other.

In order to speed up the process of leveraging Windows users over to IE, Microsoft exploited its position amongst PC and retail internet service providers (ISP) distributors to ensure that IE, not Navigator, was the first browser that general users would come into contact with. If, by exploiting its market power in the distribution channels, it could attract the vast majority of new internet users (whose numbers were expanding exponentially every 12 months), then it could rapidly expand its market share in the browser market. To this end, Microsoft set up a series of exclusivity deals with the leading original PC manufacturers to ensure that its browser was automatically bundled with new PC packages. Microsoft simultaneously set

[5] US Department of Justice Exhibit No. 233, an internal Microsoft document titled 'IE 5 OEM Marketing Plan', indicates that Microsoft later planned to integrate virtually every piece of Microsoft application software.

up exclusivity deals with the major retail ISPs in order to ensure IE was subscribers' automatic default browser. As with the hardware PC market, a small number of very large providers dominate the retail ISP market. Here, Microsoft's strategy comprised two parts. The first involved a heavy investment in setting up its own 'Microsoft Network' to establishing itself as a major ISP. The second involved striking a series of exclusivity and cross-advertising deals with the three other major ISPs: America Online (AOL), Internet MCI and CompuServe. In exchange for Microsoft listing their services on its Windows Internet Connection wizard, these ISPs agreed to offer IE as their standard default browser. It was these exclusivity and cross-advertising deals with PC manufacturers and retail ISPs that brought Microsoft into conflict with the US anti-trust authorities.

In sharp contrast with Microsoft, Netscape had a very weak position. Originally, licensed versions of NCSA's Mosaic had been distributed through traditional retail channels by the leading PC hardware manufacturers and ISPs within a package of internet tools that included dial-up access and e-mail, as well as the NCSA browser. When Netscape was founded it was a late market entrant in the first browser war without an established position in the traditional retail channels. Rather than seeking to build a position, Netscape sought to sidestep these channels by using the internet itself to distribute its product. In so doing, the company enjoyed almost zero variable costs. Cusumano and Yoffie (1998) suggest that this innovative strategy effectively turned a weakness into a strength. Yet Microsoft's ability to subsequently exploit its own advantage in this area raises a serious question mark against this. Further, Microsoft's strategy gave it a competitive edge with respect to the non-pecuniary costs associated with acquiring IE. Searching for and downloading Netscape Navigator over the internet (a non-trivial issue for many new general users) implied a positive set-up cost, whereas Microsoft IE was automatically bundled with PC and ISP software. Netscape's distribution strategy assumed that users already had an internet connection, together with a high degree of technical proficiency and self-confidence. Microsoft's strategy did not.

Each of the four elements of Microsoft's strategy—the development of a comparable but technically incompatible rival product, the cross-market leveraging of installed user bases, pecuniary and non-pecuniary costs—were complementary and, together, proved highly effective in overcoming the early advantage enjoyed by Netscape. By January 1998 IEs share of the market had already risen to 39%, up from 21% in January 1997 (Statmarket, 1999; Newman, 1998). The number of computers installed with Netscape grew by just 33% during 1997 while the number installed with IE almost tripled, indicating Microsoft's success in capturing the vast majority of new users. Netscape's problems were confirmed when it announced a fourth quarter loss of US$ 88.3 million for 1997, bringing its total loss over the year to US$ 115.5 million, followed by the announcement of a decision to axe 400 jobs in January 1998. Carrying these unsustainable losses, Netscape was the subject of a successful take-over bid by America Online in November 1998, effectively bringing the second browser war to a close. The attraction of the Netscape acquisition for AOL was the Netcenter portal website, not its browser technology. AOL was already the largest portal on the Web with 14 million subscribers, the majority being consumers. Through the acquisition of Netcenter it gained a further nine million registered users, a large proportion of which were corporate registrations. This effectively gave AOL 60% of all Internet subscribers and an unprecedented opportunity to bringing together consumers and businesses. Rather than supporting Netscape's browser technology, AOL has continued to offer IE as its default browser.

3. Modelling the browser wars

In order to analytically examine the various supply and demand side factors that influenced the outcome of the Netscape–Microsoft standards battle, this section of the paper presents a model that develops and extends Arthur's Polya Urn model of technological lock-in. Developed in association with Ermoliev and Kaniovski (Arthur et al., 1985, 1987), the model considers standards competitions between rival, contemporaneous versions of new technological artefacts. The case of two rival variants of a new technology (A and B) corresponds to urn schemes containing balls of two colours. A large number of balls are sampled with replacement, i.e. for each ball of a particular colour drawn, an additional ball of the same colour is added to the urn. With the urn scheme, one can represent non-stationary Markov chains with a growing number of states; market share being a process X_t that develops on a one-dimensional simplex (0,1) taking (discrete) values from a set of rational numbers from (0,1). In each period $t = 1, 2, 3, \ldots$, one new adopter enters the market. Each adopter is boundedly rational and risk-averse. In Arthur et al. (1985), technologies are symmetric (i.e. of comparable quality) and agents base their decisions on the current market share of each technology. Hence, a new adopter will choose variant *A* if the majority use *A*. Otherwise (s)he will adopt variant *B*. This decision rule generates the probability function:

$$f_t(x) = p(x) + \delta(x) \quad (1)$$

where

$$p(x) = \sum_{i=(r=1)/2}^{r} C_r^i x^i (1-x)^{r-i},$$

with C_r^i the number of combinations from r to i, and $\sup_{x \in R(0,1)} |\delta_t(x)| \leq \text{const} \min(x, 1-x) t^{t-1}$.

The function $p(x) - x$ has three roots: 0, 1/2 and 1 on (0,1). Of these, only roots 0 and 1 are attainable as $t \to \infty$.[6] This provides the basis of the Arthur–Ermoliev–Kaniovski (AEK) theorem, which states that the adoption process will always converge to one or other competing variant, with a probability of one, resulting in a market monopoly. David (1997) observes it is not the limiting states that have generated interest but the implications of stochastic processes. Ex ante, it is impossible to predict which particular variant will emerge as the winner, the final outcome depending on the sequence of adoptions that are built up over time. "Under unbound increasing returns, the dynamic process... takes on a truly historical nature in the sense of being *non-ergodic*; it can never shake loose from the grip of past events and is in this sense *path-dependent*" (David, 1997, p. 226). Chance events, that in the early stages nudge the competition slightly in favour of one or other alterative, are magnified over time, fundamentally affecting the final outcome. This path dependency is not an assumption or a structural condition of the model but a property of the stochastic process described by the Polya Urn model.

David (1985) and Arthur (1988) have suggested that stochastic processes can lead to markets selecting inferior quality variants. This can occur if the network externality associated with the inferior variant outweighs the quality differential between it and the competing variants. The QWERTY keyboard (David, 1985) and DOS (Arthur, 1988) are held up as examples of variants that have won technological standards battles despite their being widely recognised to be technically inefficient and inferior to alternative designs available at the time. This suggestion has triggered a debate, with contributions by Katz and Shapiro (1986), Farrell and Saloner (1985), and Liebowitz and Margolis (1990).[7]

In its original form, the Arthur model does not enable one to consider differential pecuniary and non-pecuniary costs, or the impact of cross-market externalities on standards competitions. Further, the applying the model to a complex technology such as the internet requires a careful definition of the 'market' under investigation. The original model assumes there is an autonomous market for a single product. As discussed above, we are currently concerned with a set of interrelated product markets. In the Netscape–Microsoft case, this may be simplified to a discussion of two interrelated technology markets, the browser market and the operating system market, each of which contains two rival product variants. To simplify, let us assume that competition in the operating system market z is restricted to two rival alternatives: Unix-based operating systems (z_{U}) and Windows (z_{W}).

Competition in the browser market x is similarly between two alternatives: Netscape (x_{N}) and Microsoft (x_{M}). As in the original model, one new adopter enters the market in each period and must choose one or other browser. In this manner, we can formally analyse the Netscape–Microsoft battle using model containing two, coupled Polya Urns. Let λ be the strength of

[6] Attainable points exist where, for a root θ of $f(x) - x$, there is convergence of X_i to θ with positive probability $(f(x)-x)(x-\theta) \leq 0$ in the neighbourhood of θ. Unattainable points exist where there is convergence of X_i to θ with zero probability $(f(x)-x)(x-\theta) \geq 0$ in the neighbourhood of θ.

[7] While interesting, this particular debate is of direct relevance to the current paper. Here, we are considering two products of approximately equivalent quality.

interaction between the adoption decisions made in the browser market x and the adoption decisions in the operating system market z. The strength of the network effect for a particular variant of the browser technology will therefore be co-determined by the user's choice of operating system variant, z_U or z_W, and the strength of the interaction term λ. An initially large share of the installed user base for one or other browser—even 90% share such as that initially enjoyed by Netscape—is no longer sufficient to ensure a technological lock-in. As discussed in the previous section, the installed Windows (z_W) user base dwarfed the installed user base of the Netscape browser (z_U). Maximising λ_{xz} through the integration of its IE and Windows software, Microsoft was able to leverage its installed Windows user base across to the browser market.

Turning to the costs associated with acquiring the competing browsers, in Arthur's original model (1) this is reduced to a utility function. This is a useful simplification when price differentials and the initial set-up costs (e.g. time and effort for search and installation) of the rival products do not differ significantly. However, if either the pecuniary cost (c) of acquiring the technology or the non-pecuniary investment costs (i) associated with acquiring and setting up the technology affect adopters' choices, then Eq. (2) needs to be expanded such that the value for money of technology j depends on c_j and i_j. Together, these decision rules generate the probability function:

$$f_t(x) = \frac{p(x) + \lambda z}{c + i} \tag{2}$$

The function has two roots, 0 and 1, that are attainable as $t \to \infty$. The probability of choosing Microsoft as a function of x_M is

$$f(x_M) \begin{cases} 1 & \text{if } \dfrac{p(x_M) + (\lambda_{MW} z_W)}{c_M + i_M} - \dfrac{p(x_N) + (\lambda_{NU} z_U)}{c_N + i_N} \geq 0 \\ 1 & \text{if } \dfrac{p(x_M) + (\lambda_{MW} z_W)}{c_M + i_M} - \dfrac{p(x_N) + (\lambda_{NU} z_U)}{c_N + i_N} \leq 0 \end{cases}$$

The roots of this model are very different to the roots of Arthur's original model. The probability of adopting a particular variant not only depends on the number of previous adopters x but also λ, z, c and i.

Let us calibrate the model for the Netscape–Microsoft browser war. The competition comprises two distinct periods: period 1 and period 2. Period 2 begins when Netscape reaches a market share of 90%, and ends when Microsoft achieves an 80% market share. Initially, Microsoft and Netscape start with equal market shares (here, we simplify by not including NCSA). In period 1, $\lambda_{NU} = \lambda_{MW} = 0$: the browser is a stand-alone product and there is no link between the browser and the operating system markets. Thus, a single urn is effectively operating in period 1. By contrast, a coupled urn model operates in period 2. $\lambda_{NU} = 0.01$ and $\lambda_{MW} = 0.5$ reflecting the different extent to which Netscape and Microsoft

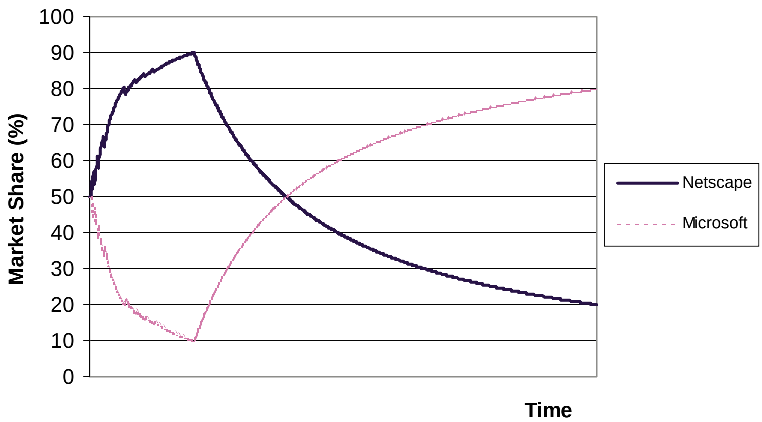

Fig. 1. Example of diffusion pattern generated by a coupled Polya-Urn model.

were seeking to integrate their browsers with Unix and Windows operating systems and, hence target these communities. As discussed in Section 2, Microsoft's strategy was clearly devoted to integration with Windows, while Netscape's plans were the long-term development of a multi-platform browser with Sun. $z_U = 100$, and $z_W = 900$, reflecting the installed user bases for Unix and Windows in the operating systems markets. Turning to the pecuniary costs of acquiring the Netscape and Microsoft browsers, $c_N = c_M = 0$ in periods 1 and 2 since both companies generally pursued a policy of giving away their browsers. As discussed in Section 2, the technical competence of early adopters meant they were indifferent as to whether the browser was distributed via traditional channels or via the internet. However, for later adopters with less technical competence and less confidence in downloading software, the non-pecuniary costs of acquiring Netscape browser over the internet were greater than for Microsoft's IE. Hence, in period 2 $i_N = 0.5$ and $i_M = 0.1$. Fig. 1 illustrates the type of output generated by the calibrated model. We find that for these particular values of λ, z, c and i there is just one outcome: victory for Microsoft.

4. Conclusion

Extant theory tells us that late market entrants can win technological standards battles by introducing products with superior quality/price performance. This cannot explain, however, the second browser war between Netscape and Microsoft. This particular case study highlights the importance of identifying and exploiting linkages between the vertically related products that make up a technology system. In particular, Microsoft's linking of two product markets—the browser and the operating system—enabled it to exploit market power in one market in order to win a standards battle in the other. Further, in order to speed up the process, it exploited its advantage in distribution to ensure that new internet adopters were automatically offered its browser when they acquired a new PC or registered with a major ISP. With regards to quality and price, Microsoft's strategy involved the development of a browser of approximately comparable quality and price. They were not superior, however.

In order to examine the dynamics of the Netscape–Microsoft war, a coupled Polya Urn model was developed. The results of simulations conducted on the model clearly indicate the powerful, and rapidly acting, consequences of cross-leveraging installed user bases between vertically related markets. In particular, it highlights the ability of Microsoft's strategy to at once nullify Netscape's initial advantages. This paper considered the case of two rival variants in two vertically related markets. However, the model can be extended to a greater number of markets (urns) and a greater number of competing variants. Such an extension would be useful in addressing strategy formation for the internet and other complex technology systems. For example, one could analyse the circumstances under which a competitor could overcome Microsoft's monopoly in the browser and operating system markets. At first glance it would seem that AOL missed an opportunity to mount a challenge, following its acquisition of Netscape. However, qualitative inspection of the model suggests that AOL made a wise decision. To begin with, Microsoft's combined IE-Windows user base dwarfs that of AOL-Netscape. Second, AOL would need to develop a technical proprietary link between its portal software and the Netscape browser that could not be emulated by Microsoft. This is unlikely. Indeed, Microsoft's proven ability to match Netscape's browser means AOL could not necessarily expect to gain a competitive advantage through investment in further R&D. Finally, despite AOL's leading position in the ISP market, Microsoft's has superior control of the conventional distribution channels through its deals the leading PC distributors and ISPs.

The browser case study provides a precautionary note to recent research on open software standards and innovation networks. Much of the recent literature on Linux, for instance, has suggested a tendency towards the development of open platform standards. Yet here is an example of an initially open, non-proprietary standard being captured, first by Netscape and then by Microsoft, in order to strengthen their position within the software industry. The case study illustrates there are strong private gains in capturing a key component of a technology system. Clearly, more critical research is required in this area. Similarly, the case study suggests more caution needs to be taken with respect to strategic alliances for innovation. Much has been written about innovation networks and the potential benefits associated with this particular mode of organising technological innovation. Netscape established strategic alliances and carefully managed its relationship with third-party providers. Yet, it was Microsoft who won the browser war. It is therefore not clear, ex ante, whether collaborative innovation is more efficient than the internal coordination of innovation.

To summarise, the browser battle opens up important new insights into the dynamics of technological competitions in which the leveraging of cross-product externalities play an important role in determining the final outcome. The case study calls for a reappraisal of some of the lessons that have been drawn from previous work on technological lock-in. In particular, future research will need to distinguish between autonomous technologies and complex systems that comprise a number of related technologies. The strategies employed by Microsoft have important implications, both for lock-in theory and for managers seeking to apply its lessons in technological competitions.

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