PLATFORM COMPETITION: A RETRODUCTIVE SYSTEM DYNAMICS MODELLING APPROACH

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ABSTRACT

Competition between technology standards for market share is a complicated phenomenon where a large number of factors have an impact on the outcome according to the literature. Inevitably studying their influence, for example the timing of market entry, is a challenge. The generic simulation model presented here builds on previous work and is applied to four cases of standard competition from the literature. Following a retroductive research design, reproducing the results of each case the model provides support for the soundness of the underlying theoretical framework used to analyse the case studies. It thus increases the confidence in its validity and provides a formal basis for further empirical and theoretical work.

Key words: standards, competition, system dynamics.

INTRODUCTION

Competition between market-based interface standards is a complicated phenomenon whereby, according to the literature, a large number of factors have an impact on its eventual outcome. Standard competition is characterized by inherent uncertainty, path dependency and switching costs (Burnham et al., 2003). The temporal frame in which they take place is also getting smaller. For example competition over the width of railroad tracks took decades to settle while battles over standards in communication nowadays take considerably less time (Van de Kaa, 2009). When interface standards are established the interoperability of the distinct technology components they enable, facilitates innovations in the form of e.g. new systems becoming possible. For example the establishment of railway standards brought fundamental changes to cities, infrastructures and the way people lived and commuted.

In every case, distinct factors mentioned in the literature are integral to how the endogenous dynamics in such situations play out (Schilling, 1998; Christensen et al., 1998; Shapiro and Varian, 1999). A recent comprehensive review of the literature and previously proposed frameworks discusses 29 factors that have a positive or negative effect on standard dominance (Van de Kaa et al., 2011). Consequently in the standard competition cases where the framework has been applied so far, a question naturally arises: Does the combined effect of the factors that are thought to have an effect actually produce the observed outcome?

There are certain challenges in answering this question. There is clear evidence of a continuous increase in the number of factors and therefore complexity that various frameworks have identified as influential in standards competition (Van de Kaa et al. 2011). Inevitably, it becomes harder to assess the combined effect they have on the outcome of the competition and provide a consistent
story of how a standard eventually becomes dominant since there may be more than one combination that can seemingly produce the same outcome. In addition after several years of considerable growth the field of standard competition may be ready to move from qualitative studies to quantitative studies. This leads to considering modelling and simulation as a way of providing a better understanding of the factors for standard dominance.

This paper develops a generic simulation model utilizing the factors for standard dominance which builds on previous work on modelling standards battles (Papachristos and van de Kaa, 2014). The generic standard competition model developed in this paper, is a formal framework that represents complex, dynamic cause/effect relationships. The model represents the organizational processes, decision making and behavior of standard supporters and standard adopters as well. It is tested in four format competition cases detailed in van den Ende et al. (2012) and van de Kaa and de Vries (2014): (i) Firewire vs USB, (ii) Wifi vs HomeRF, (iii) MPEG vs AC 3 and (iv) Blu Ray vs HD dvd.

The research design of the paper follows a retroductive approach (Sayer, 1992). A dynamic hypothesis is constructed integrating all the factors identified as important in the framework of Van de Kaa et al. (2011). This is transferred into a quantitative model. Four instances of the model are then created and calibrated using data of each of the four cases keeping the model structure is kept identical. The implications of the dynamic hypothesis adapted to each competition case, are deduced by means of a system dynamics model. The simulated competition results are in agreement with real world outcomes. The contribution of the paper is twofold. To our knowledge, it presents the first formal model of standard competition that is tested in four cases and the results of the simulation under a retroductive approach provide further support to the standard competition framework of van de Kaa et al. (2011). The same approach can be repeated following any framework on standard competition.

METHOD

Retroduction is a different mode of reasoning than deduction and induction (Wuisman, 2005). It is a metaprocess through which an empirical phenomenon is explained as the outcome of generative mechanisms that operate under certain conditions (Sayer, 1992). Demonstrating generative causality is the idea that ensembles of causal mechanisms possess the power to influence reality and/or the tendency to exhibit particular behaviours and generate events that are experienced at the empirical level through human senses. It follows that creating knowledge about a phenomenon is produced by uncovering these mechanisms and their causal powers. They may or may not be active, hence the set of empirically observed events is smaller than the set of possible events. This leaves room for considering different outcomes or pathways than those the system actually produces depending on which mechanisms are operating each time in different cases.

Generative mechanisms are thus real and distinct from the events and patterns they generate and in turn events are real and distinct from human experiences by which they are cognised (Bhaskar, 1998). Hence, their existence is not entirely dependent upon them being observed (Sayer, 1992). Drawing on critical realism, social reality is not necessarily equivalent, nor reducible to explanations or interpretations of phenomena that draw solely on the empirical level (Wuisman, 2005). Consequently, arriving at explanations about observed events is an incremental process i.e. causes of phenomena that are situated at different layers are not discovered all at once. Furthermore, valid
general explanations hold only to the extent that social mechanisms persist in time and are active across cases and social contexts. This is why in this paper we explore four different cases.

The observed events are the outcome of all the mechanisms operating simultaneously that may not necessarily have an empirically manifest outcome when operating separately (Archer et al., 1998). Hence, in order to understand why a phenomenon unfolded the way it did, or whether it could unfold in a different way, it is necessary to construct a hypothesis where an ensemble of generative mechanisms interact systemically in a particular way or in another (Collier, 1994). These are then subjected to empirical scrutiny and their explanatory power is evaluated against competing explanations (Wuisman, 2005). This is the core idea underlying retroduction as a method for explaining phenomena and uncovering generative mechanisms.

**FACTORS IN FORMAT BATTLES**

The study of van de Kaa et al. (2011) classifies factors relevant to format dominance under five categories: (i) ‘characteristics of the format supporter’, (ii) ‘characteristics of the format’, (iii) ‘format support strategy’, (iv) ‘other stakeholders’, and (v) ‘market characteristics’. These are briefly summarised in order to provide the background for the model. This is adopted from Van de Kaa, et al (2011) and Van de Kaa and de Vries (2014). For further information concerning the factor we refer to these papers.

‘Characteristics of the format supporter’ are complementary assets that are key to winning a standards battle and include financial resources, reputation and credibility, operational resources, and learning. ‘Characteristics of the format’ include technological characteristics, compatibility, the availability of complementary goods, and flexibility. ‘Format support strategies’ includes pricing strategy, appropriability strategy, timing of entry, marketing communications, pre-emption of scarce assets, distribution strategy, and commitment. The other stakeholders category includes the installed base of current and previous format versions and large and powerful stakeholders (‘big fish’) that may adopt the format and in doing so increase its installed base. Furthermore, regulatory and anti-trust judiciary interventions may also affect the end result of format competition. Van de Kaa et al. (2011) also mention the number of suppliers of complementary goods and the effectiveness of the (formal) standard development process as important factors. Finally, certain aspects of the network of format supporter may be affecting the success of the format. The fifth category includes the factors that indirectly affect format dominance: network effects, bandwagon effects, number of competing formats and the speed of change in a market which both affect the uncertainty in the market, and the switching costs.

In order to build a coherent overarching picture of how all of the factors discussed in section 3 are implicated in one format becoming dominant, the fragmented causal relationships identified therein, are laid out in one coherent CLD. In the paper by van de Kaa et al. (2011) the factors were explicitly and directly linked to format dominance. No attempt was made to link them and present a more integrated picture. The assumption carried forward in this paper is that these are linked and interact. Inevitably there may be more than one steps between each factor and format dominance or more than one ways in which each one can influence format dominance. Additional assumptions have to be made to include causal links between a factor and its effect on the outcome of the format battle in order to build a CLD where the dynamics arise endogenously. These are distinguished in Figure 1 (dotted lines) from those identified in van de Kaa et al. (2011) (solid lines). Finally the
original numbering of factors discussed in van de Kaa et al. (2011) is maintained so they can be traced back to the original framework. The CLD has been broken down in two parts for reasons of clarity. The first presents the factors of format supporter characteristics, format characteristics, support strategy. The second presents those of other stakeholders and market characteristics.

Starting at the bottom of Figure 1, Format_Selection leads to an increase in the Current_Installed_Base which with a certain delay it becomes the Previous_Installed_Base. Its magnitude provides an indication of success in setting formats (Past_performance_in_Setting_Formats). It creates a stock of experience (Past_Experience) upon which the firms and the users involved can rely in the future and improve their Core_Capabilities and Absorptive_Capacity leading to greater Effectiveness_of_Format_Development_Process and to Format_Selection.

Increased Past_Performance_in_Setting_Formats improves the Financial_Strength of the format supporters which can be used to influence Customer_Expectations or implement Low_Pricing strategies in order to discourage further competition. Financial_Strength can be an exogenous parameter for new formats that enter into competition but for those already existing in the market it is assumed to be built up based on revenue coming from current and past format adopter bases. It also increases the Commitment that format supporters exhibit. This counteracts the tendency of firms of committing to several formats in order to hedge against uncertainty and risk in the early stages of format competition when a number of formats are available (Adner, 2006).

High Financial_Strength enables format supporters to acquire scarce resources and thus increase their Technological_Advantage and/or provide them with a Superior_Production_Capacity that can confer an advantage in terms of quality and performance over its competitors. High Past_Performance_on_Setting_Formats reinforces Brand_Reputation which may attract additional stakeholders into the format support group. This can increase the installed base for the format either by implementing it in their products or by producing Complementary_Goods for it. Network_Externalities depend on the magnitude of current and previous installed customer base and have a positive effect subject to subject to Compatibility and Appropriability_Strategy. The range of Complementary_Goods available also increases Network_Externalities and is related to the regulatory framework that might prescribe certain formats or complementary products (Axelrod et al., 1995). Format supporters can also influence the perception of customers about Switching_Costs by raising their expectations through Marketing_Communications. These can eventually become a self-fulfilling prophecy so that the format that is expected to become dominant will actually become dominant (David and Greenstein, 1990). For example, in the early phase of a battle, pre-announcements about format characteristics or about its imminent adoption by firms can discourage users from adopting a rival format and thus deny market share to competitors (Farrell and Saloner, 1986). Marketing_Communications reinforce the customer’s perception of those format features that differentiate it from its competitors, thus increasing customer switching costs and reducing their search for alternatives (Heide and Weiss, 1995; Weiss and Heide, 1993).
Figure 1 CLD: format supporter characteristics, format characteristics, support strategy

In Figure 2, the Diversity_of_Stakeholder_Network leads to an increase in the range of Complementary_Goods which influences Switching_Costs, as users may be required to learn to use all the complementary products that are involved in switching to the new format (David, 1985). When there is already an installed base of format users, this inevitably means that users at some point have to switch from one format to another and thus switching costs is a factor that has to be taken up explicitly in the model. The effect of these switching cost factors is assumed to be reinforced by the Appropriability_Strategy that format suppliers follow i.e. the actions taken to protect the format from competitor imitation. The level of compatibility between formats works in the opposite direction (van de Kaa, et al., 2011).

Format selection is also contingent on the Bandwagon_Effect whereby users provide positive feedback based on their experiences and influence potential customers by social contagion (Sterman, 2000). A High_Rate_of_CHANGE implies that new format generations are introduced frequently, thus lowering format supporter Commitment to any of them. Furthermore, a high rate of new format introduction keeps customers from making a choice since they may wait for the next better version or they may be unable or unwilling to keep up with the rate at which format features are updated or change.

When Uncertainty_in_the_Market gets too high firms and customers are less willing to risk choosing and committing to one particular format and they postpone their decision. This decreases both the likelihood that dominance of one format will be reached and the speed at which this format will achieve dominance. Antitrust_Laws can prohibit certain formats from becoming dominant. Finally, particularly influential actors (Big_Fish) can tilt the balance in the market in favour of a format by
promoting, adopting or financially supporting it. Action by Regulators can also have the same effect when a particular format is prescribed for use.

**Figure 2 CLD of other stakeholders and market characteristics**

**A MODEL OF FORMAT COMPETITION**

A system dynamics model based on the CLDs discussed also in previous work (Papachristos and van de Kaa, 2014) was developed in Powersim © (Sterman, 2000) (code available upon request). In order to model switching costs between formats, the typology of Burnham et al., (2003) was applied. The research of Burnham et al., (2003) discusses a number of factors that directly influence switching costs and the intention of customers to stay with a particular supplier. One of them is the extent to which the consumer employs a variety of product types, features and functions offered by a supplier. In this paper this is assumed to include products that are complementary to the core product that is in use. This increases procedural costs i.e. the economic risk, the effort in evaluating, learning and setting up involved in switching to a new product. It also increases the financial costs for customers that consist of the benefits that the customer has to forego and the financial resources that have to be expended for the new product (Hypothesis 3 in Burnham et al., 2003).

Another factor is product complexity. It results in customers having difficulties in compiling relevant information and evaluating a product. At the opposite end of the spectrum greater user experience and knowledge about the various products, features and functions offered in the market reduces the uncertainty associated with switching to a new supplier as customers are able to accurately evaluate products and understand related information. Burnham et al., (2003) confirm that it reduces the uncertainty associated with using a new format and results in lower procedural and relational costs.

The effect of product complexity and user experience under uncertainty in evaluating and choosing a particular product is included in the model but it is not assumed to influence switching costs directly because uncertainty in evaluating a product may lead the customer to perceive one as superior when in fact this is not the case. This effect has been modelled following the formulation of Loch and Huberman, (1999) for assessing the level of performance of the new technology. The randomness introduced in path-dependent system stands for events outside the boundary of the model—that is, those events for which there is no causal theory (Sterman, 2000). A random component $f_t$ is used that has a symmetric exponential distribution with parameter $\beta$ and density given by:

\[
\frac{1}{\beta} e^{-\frac{x}{\beta}}
\]
\[ f_x(x) = \frac{1}{2} \beta e^{-\beta x} \text{ for } x \geq 0 \quad (1) \]
\[ f_x(x) = \frac{1}{2} \beta e^{\beta x} \text{ for } x < 0 \quad (2) \]

\( f_x \) has zero mean and variance \( \frac{1}{\beta^2} \). Each customer evaluates the format separately and independently, so the random components across customers are independent and identically distributed random variables. Hence the same uniform distribution is used for \( x \). The uncertainty diminishes as the format diffuses in the market and its performance becomes well understood.

Another factor in users changing between formats is their prior customer switching experience. The greater the number of suppliers a customer has had in the past, the smaller the switching costs he will face, for two reasons. First, it increases customer experience about the switching process itself and using new products. Second, frequent switching inevitably implies that the customer interacts with each supplier for less time, thus the benefits accruing through this relationship are smaller and therefore easier to forego. The switching experience of customers has been modelled as the cumulative stock of past switching events. A switching event takes place when the customer installed base trend for a format increases or decreases. Thus total switching events change in proportion to the 1st order derivative of market base.

Finally user satisfaction is important. Greater user satisfaction keeps them from switching products (Burnham et al., 2003). User satisfaction \( U_s \) with a particular format is assumed to depend on the product of Operational_Competence (OC) and the range of Complementary_Goods (CG). The logic is that a technically superior product with a wide range of complementary goods has an advantage over competition. Following Burnham et al., (2003) there is no direct relationship in the model between \( U_s \) with product and switching costs. The intention of customer to persist with a particular format choice \( I_i \) has been formulated in the model as:

\[ I_i(t) = U_i(t) \times (S_p(t) + S_r(t) + S_c(t)) \quad (3) \]

Where \( S_p \): switching procedural costs, \( S_r \): switching financial costs, \( S_c \): switching relational costs. The general case of network externalities \( N_e \) effect has been modelled as:

\[ N_e(t) = P_b \times C_i \times CG(t) \times A_i \quad (4) \]

Where \( P \) is Previous Installed Base, \( C \) is Compatibility and \( A \) is appropriability strategy. The logic this equation embodies is that network externalities depend on the previous format installed base to the extent that format compatibility is high and there are many products on offer that are complementary to the core product. The effect of network externalities and complementary products in particular, is moderated by the appropriability strategy that format supporter firms adopt i.e. all the actions that firms undertake in order to protect a format from competitor imitation (Lee et al., 1995). If the appropriability strategy is strict then this inevitably restricts the development of complementary products as well. If there is no previous installed base as in cases 1, 2 and 4: \( N_e(t) = CG(t) \times A_i \quad (4) \)

**MODEL VALIDATION**

Model testing in order to establish confidence in the validity of the model is standard practice in system dynamics (Barlas 1996; Sterman, 2000). Boundary adequacy tests have been part of the development process of the model from the very start since the intention was to link the causal
factors that influence format competition so that the outcome can be generated endogenously. Other tests include, dimensional consistency, extreme conditions where high or low values where assigned to input parameters, numerical sensitivity to simulation time step and sensitivity analysis discussed in section 7. In addition the model exhibited the S diffusion pattern for all cases.

Furthermore, drawing on the framework that the model is based on, it follows that in a competition between two formats, the one that has a slight advantage in one of the factors listed should become eventually dominant ceteris paribus. This was tested with a deterministic version of the model where each factor was increased for Format 1 keeping the rest equal for the two competing formats. The results are in agreement with the framework. Figure 3 presents the factors of the framework that have been used as exogenous input for calibrating the model to each case. The original numbering in van de Kaa et al., (2011) has been retained.

The opposite test was also carried out i.e. with no difference between two competing formats there must be no difference in the end market shares the two formats achieve in the deterministic version of the model and no statistically significant difference in the stochastic version.

**Figure 3 Test of deterministic factor influence on standard dominance**

**SIMULATION RESULTS**

Drawing on the preceding discussion of factors influencing format competition, the current section sets out to explore whether the factors identified in each of the four format competition cases considered are necessary and sufficient to reproduce the outcome of the competition. Thus two research questions are set out.

i. Are all the factors involved in the proposed explanations developed for each case actually necessary and sufficient in order to reproduce the outcome of the case?

ii. What is the range of values under which this holds, given that set up values in the model were estimated from qualitative cases, rather than using hard data as input?

The factors deemed important in each case are given in Table 1 with the initial numbering of factors from van de Kaa et al., (2011) given for consistency. The input values used for variables were set based on a qualitative understanding of each case and are provided along with the simulation time
for each case. Values for flexibility and diversity of stakeholder network have been included as exogenous time series (Appendix A). Each case set up is simulated 100 times.

Table 1 Factors relevant in case 1 and input values in corresponding variables

<table>
<thead>
<tr>
<th>Case 1 simulation time</th>
<th>24 years</th>
<th>Firewire</th>
<th>USB</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Technological superiority - learning</td>
<td>0.1</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>5 Technological superiority - Initial Technical &amp; Market Know How</td>
<td>6</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>11 Competitor Entry Timing</td>
<td>1</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>15 Level of Commitment</td>
<td>0.1</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case 2 simulation time</th>
<th>25 years</th>
<th>Wifi</th>
<th>HomeRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Technological Superiority Learning</td>
<td>0.2</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>5 Technological superiority - Initial Technical &amp; Market Know How</td>
<td>0.4</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>11 Competitor Entry Timing</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>12 Marketing Communication</td>
<td>0.2</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>15 Level of Commitment</td>
<td>0.3</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case 3 simulation time</th>
<th>24 years</th>
<th>MPEG</th>
<th>AC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Brand reputation - Past Performance in Setting Formats</td>
<td>0.2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5 Technological superiority learning</td>
<td>0.1</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>5 Technological superiority - Initial Technical &amp; Market Know How</td>
<td>0.4</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>6 Compatibility between Format Generations</td>
<td>1</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>7 Initial Complementary Goods Rate</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>12 Marketing Communication</td>
<td>0.1</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>15 Level of Commitment</td>
<td>0.1</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>17 Previous installed base</td>
<td>12</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case simulation time</th>
<th>13 years</th>
<th>Blu Ray</th>
<th>HD DVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Brand reputation - Past Performance in Setting Formats</td>
<td>1</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>15 Level of Commitment</td>
<td>0.6</td>
<td>0.3</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4 on the left shows simulation results for the Firewire vs USB case. Due to the stochasticity incorporated in the model the results for market share show some overlap. Nevertheless, statistical testing reveals that the difference between the average end market share values is significant (p<0.001). What has a direct influence on this is the magnitude of uncertainty parameter beta $\beta$ which is set at 8 for all cases. What is evident is that for values greater than 8-12 the effect of uncertainty attenuates the effects of loop dominance to a certain extent and results become more erratic as the average and standard deviation show (Figure 4 right).

![Figure 4 Simulation results from case 1: Firewire vs USB](image_url)

Figure 5 shows simulation results for the Wifi vs HomeRF case. There is no overlap in the results for the entire range of uncertainty used in the model. Again there is a certain convergence in end market share of formats and increase in range of outcomes indicating the effect of uncertainty on outcome competition.
Figure 5 Simulation results from case 2: Wifi vs HomeRF

Figure 6 shows results for the MPEG vs AC3 case. Despite the initial advantage that MPEG enjoyed with an already installed base, the outcome of the competition is clear.

Figure 7 shows results for the Blu Ray vs HD dvd case. Overall they are quite similar with previous figures the only visible difference being that the s shape diffusion curve is noticeably smoother. It takes longer for any considerable advantage to develop in favour of the Blu Ray and that is because only two factors where assigned values in order to reproduce the case: brand credibility and level of commitment.

Overall simulation of the four cases shows that for the particular set up of parameter values adopted the model can reproduce the outcome of the competition in each case. While the model is stochastic, uncertainty in user format evaluation is not sufficient to alter the results in any case. It does result in converging values for format market share. This is to be expected as greater uncertainty in format evaluation causes some users to choose inferior formats and in effect this disrupts the reinforcing loops form giving an early path dependence advantage to a format. Nevertheless, causality coming from the influential factors identified in each case overcomes this effect.

Figure 6 Simulation results from case 3: MPEG vs AC3
Figure 7 Simulation results from case 4: Blu Ray vs HD dvd

The results are not to be interpreted as providing numerical indication of the market shares. An important assumption is that market segments have been kept separate with no user flows between them. In reality the market shares of the dominant format can be expected to grow further and that of the looser to decline particularly if firms have completely withdrawn their support for the format as in the case of HD DVD.

SENSITIVITY ANALYSIS

Sensitivity analysis is a standard part in all simulation studies. In this paper there is an additional reason for carrying it out, as the calibration of the model was based on a qualitative assessment of each case and the values used as an input were meant to reflect the relative difference in the influence each factor on each format.

The following figures present sensitivity analysis results for all the cases, where all of the input variables are varied. Because the complete value space explored is considerable, results here are shown only for min and max values assigned to each variable (see Appendix B for details). The logic for setting the range of parameters P values is that for factors where format Fi has an advantage over Fj then sensitivity starts by setting Pi = Pj and then varying Pi only, always maintaining that Pi >= Pj. Each set up was simulated 40 times and the following figures show results for the end market share of each format.

In the case of Firewire vs USB there is an interesting alternating pattern to the results (Figure 8). This persists with (left) and without (right) external time series input for flexibility and network diversity that favours USB and tends to counter somewhat the effect of Firewire’s early entry into the market. Firewire entered the market in 1987, seven years earlier than USB. Nevertheless, it did not succeed in becoming dominant because the timing was not right. The effect of market entry timing is seen between setup runs 4 - 8 and 12 -16. The only difference is the level of commitment for which a higher value is given for USB in runs 9 - 16 than 1 – 8 and seems to completely counter the effect of Firewire’s early market entry. What is also evident is that technological superiority alone (runs 1 – 4) does not make enough of a difference in terms of competition outcome.
Figure 8 Sensitivity results from case 1: Firewire vs USB

Figure 9 shows the sensitivity runs for Wifi vs HomeRF. In every setup the end outcome of the competition is clear. As the magnitude of values for variables tested reaches and exceeds the ones they have for the calibrated runs, the separation between the market shares increases. The effect of flexibility and network diversity in favour of Wifi is also evident especially in runs 1 – 16 when comparing the two figures. It is also possible to assess the effect that increasing the level of commitment for Wifi has in runs 17 – 32 (Figure 9 right).

Figure 9 Sensitivity results from case 2: Wifi vs HomeRF

Figure 10 shows sensitivity analysis results for the MPEG vs AC3 case. As in the Firewire vs USB case there is a characteristic pattern in the results that suggests that some factors have an impact that is significantly higher than the rest. The figure on the left shows the complete 256 sets of runs. The figure on the right presents the first 50 sets where the average market shares are much closer. Despite the apparent complexity, the results are logical in that starting with equal values for all variables of interest, the difference between AC3 and MPEG gets larger as variable values are progressively assigned to each variable. Observing the alternation between higher and lower values for end market share (Figure 10 right) and tracing it back to the sensitivity set up the large shift in values occurring at the 17th set of runs is due to the increase in complementary goods rate for AC3. It is also evident that there is a much faster periodic pattern every 2 sets of runs and is caused by brand reputation and AC3 credibility taking minimum and maximum values in each set of runs. The effect of other variables is seen as Marketing Communication repeated every 32 sets, Level of Commitment repeated four times every 64 sets and Previous installed base repeated once after set 128. It is possible to see the effect that raising the level of commitment for AC3 has (runs 64-128) and raising the previous installed base (runs 128-256). The effect of switching off network diversity improves AC3 market share only slightly compared to Figure 10 on the right.
Figure 11 shows the Blu Ray vs HD dvd sensitivity results when assigning uncertainty beta values of 4, 8 and 12. There is no particular combination of values that alters the outcome of the competition. The characteristic increase in standard deviation and slight convergence of average end market share values observed in Figure 7 is also visible here at runs 1, 5, 9. Removing the time series for flexibility and network diversity of course in effect removes an advantage for Blu-ray and this at runs 1, 5 and 9 there is no differentiation in competition outcome.

Figure 11 Sensitivity results from case 4: Blu Ray vs HD dvd

DISCUSSION

Overall the results of the model are realistic and consistent with the case analyses. Model simulations generated the outcome of each case by assigning values only to those factors identified in qualitative analysis as having an influence while keeping the same model structure. Consequently, the question set in the introduction is answered in an affirmative way. The implication of the agreement between simulation results and case analysis that follows from the retroductive approach taken in this paper, is that modelling and simulation for each case separately shows that the factors identified in each one based on the framework of van de Kaa et al, (2011) are necessary and sufficient to generate endogenously the end result of the competition.

Analysis of the effect of uncertainty demonstrated the added value that simulation can offer in appreciating the effect each of the factors can have on standard competition in each case. Uncertainty can really obscure the potential advantage that a format can have. This is evident in the Firewire vs USB case where if the standards were slightly closer in performance then Firewire could
have dominated the market. In contrast in the rest of the cases it is evident that there could not have been any circumstances under which the outcome of the competition would be different.

Sensitivity analysis showed that in cases 1 and 3 the influence of some factors can overturn the outcome of the competition, for example the timing of market entry in Firewire vs USB. The results also show that if USB supporters did not engage in competition with considerable commitment then the outcome could have been different. In case 3 brand reputation and credibility and complementary goods factors were decisive in terms of competition outcome. The results of sensitivity analysis are important because they demonstrate that it is the combined non linear effect of factors identified in each case that produces the competition outcome and justify the question set in the introduction. The implication is that any case analysis based on the same framework that would simply add up the effect of each factors would be unreliable.

**RESEARCH OUTLOOK**

Having a sound theoretical framework is a good starting point for constructing transition “flight” simulators in order to explore “what if” scenarios about standards competition. A similar challenge in the field of strategic management, has led to the development of computer management “flight” simulators that have been applied into organisational change and resource management research (Sterman, 2000; Morecroft et al., 2002).

There are also further research questions that are worth exploring and in this respect the model structure developed in this paper can be used both for new cases and theory development. Exploring theoretical questions requires broadening the scope of the model. For example, a future extension to the work involves disaggregating customer stocks with respect to experience. This may be important in exploring firm strategies for customer retention. The idea is that customers likely to have high switching costs are those with limited experience, not those that have broad experience with formats offer or those that switch suppliers often.

Indeed customers with frequent switching behaviour are those considered as lead users, seeking to have the latest most advanced format in the market. Lead users can be important to the extent that they can constitute a critical mass and thus be the stepping stone for a broader rapid diffusion leading to rapid but risky growth path for a standard. In contrast, emphasizing the core format value, engaging existing customers with defensive marketing, increasing format complexity, introducing loyalty programs and encouraging broader use should lead to slower, sustainable growth. In order to test these stylized propositions future extensions to the model should involve at least two or three customer stocks so that the effect of lead users is captured explicitly. This line of research would provide a better appreciation of how customer satisfaction and switching costs are implicated in customer retention.

A further issue related to switching costs is the effect this can have on customer acquisition. If customers perceive a particular format as having high switching costs that would potentially lock them in for some time if they choose it, they may not choose it. Raising switching costs to retain customers may result in low customer acquisition rate especially of new, inexperienced users i.e. precisely the market segment with the greater retention potential. Lead users may have high tolerance levels to switching costs and thus it may be worth it for the company to attend to this customer segment as well. On the other hand this strategy is risky because lead users switch often. Thus an interesting issue is the trade off between switching costs and the rate of customer
acquisition. In order to explore this, disaggregating customer groups becomes necessary. Finally, it is plausible that customers try out new formats without adopting them. Thus there is scope for differentiating between trial and switching cost as well.

An important development would be to perform the same kind of study in this paper with cases of multiple format generations for example in the video game console industry and contrast it to the cases of single generation format launches that this paper has considered. What are the differences and what are the similarities?

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