Modelling interface standards battles : A retroductive system dynamics approach

Papachristos, G; van de Kaa, G

Publication date
2014

Document Version
Final published version

Published in
19th EURAS annual standardisation conference

Citation (APA)
Papachristos, G., & van de Kaa, G. (2014). Modelling interface standards battles : A retroductive system dynamics approach. In I. Mijatovic, & M. Cudanov (Eds.), *19th EURAS annual standardisation conference* (pp. 1-15). Wissenschaftsverlag Mainz.

Modelling interface standards battles: A retroductive system dynamics approach

George Papachristos, Geerten van de Kaa

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.

1. 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.

2. 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.

2.1. A retroductive methodology for format competition research

Retroduction begins with an observed phenomenon X for which no satisfactory explanation can be formed based on existing knowledge i.e. there is a theoretical gap (Figure 1). In our case X is the outcome of format competition which needs to be explained. A hypothesis H about it is formed by abduction based on a theoretical framework, which if true, would provide an explanation for X. This hypothesis has already been formed in the four cases considered in this paper in van den Ende et al. (2012) and van de Kaa and de Vries (2014). It is possible that in the process of generating an explanation more than one competing or complementary H are developed. Then, assuming that one of them holds, its validity is assessed by deducing the logical consequences of the stipulated mechanisms involved for each case. Finally, if there is correspondence between the deduced consequences and real facts determined by induction, this provides support for H. If this is not the case then a new cycle of abduction, deduction and

induction takes place. This process applied to the four cases of format competition considered in this paper, amounts to determining whether, and how, the nature, timing and intensity of interactions between factors identified in the framework of van de Kaa et al. (2011) influence the outcome of each case. Of course it is not possible to present this process here in its entirety. Just as in modelling, the reader receives the end result of what is fundamentally an iterative process (Randers, 1973). Sufficient detail is provided to replicate the approach used.

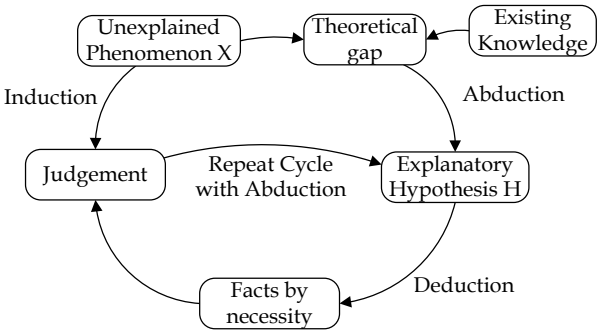

Figure 1 The cycle of discovery (based on Wuisman, 2005)

The challenge in applying this method to format competition lies in the complexity of the phenomenon under study coming from the increasing complexity in a range of frameworks in the literature (Lee et al., 1995; Schiling, 1998; Suarez, 2004; van de Kaa, 2011). Van de Kaa et al. (2011) provide clear evidence of the continuous increase in the number of factors that various frameworks have identified as influential in format competition. Inevitably, it becomes harder and harder to assess the combined effect they have on the outcome of the competition and thus provide a consistent story of how a format becomes eventually dominant since there may be many combinations that can produce the same outcome. There are a number of additional reasons why the deduction part cannot be carried out based on mental models alone and modelling and simulation should be used.

2.2. Reasons for using simulation in studying format competition

Studies of past standards competition provide an indication of the factors that might be relevant for format competition and may continue to be relevant in the future. If future format competitions resemble past ones then the framework of van de Kaa et al., (2011) will continue

to be suitable. However, the social context in which format competition takes place is ever changing. 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). It is also likely that future standards competitions will change further because environmental parameters may become decisive. The implication is that theoretical frameworks developed for standards competition need to be continuously refined, developed and tested.

Theory development aims to provide a satisficing trade off between the criteria of good theory: accuracy, generality and parsimony (Weick, 1989). Part of the challenge of format competition research, is that it relies exclusively on the construction of mental models on the part of the researchers. This reduces the effectiveness of managing research trade offs for two reasons. First, all other things being equal, the number of factors that a researcher can simultaneously maintain and trace the outcome of competition to, is smaller than that possible with a model thus accuracy and generality is compromised. Second, in scenarios about the potential future behaviour of the system, the number of influencing factors increases with the temporal horizon of analysis i.e. the system boundary grows with the time horizon. It is hard to distinguish between the factors that are influential from those that appear to be, thus parsimony is compromised. This task requires adding or removing interactions from a competition narrative and testing the effect they have.

Given the challenges at hand, qualitative analysis is not up to the task. There are inherent challenges because a number of important phenomena have to be accounted for in format competition research: processes of path dependency (Arthur, 1994; Garud and Karnoe, 2001), network externalities in product diffusion (Katz and Shapiro, 1985; 1986) and the contribution of technology formats to social welfare which depends on the level of its acceptance – network size. Unfortunately, they are not amenable to analytical treatment except from static settings (Katz and Shapiro, 1985; 1986) or simple dynamic settings (Loch and

Huberman, 1999). In the second case, the authors eventually resort to simulation because the effect of complementarities and other scale related factors is hard to ascertain otherwise. This is just one example of how modelling and simulation allows research to go beyond the range of available analytical solutions (Oreskes et al., 1994). System dynamics simulation in particular provides the means for maintaining an endogenous perspective (Richardson, 2011), and attending to all the factors involved in a competition, even if each one unfolds in a different temporal scale or it involves multi system interactions.

In its simplest form the issue of understanding format competition requires an explicit consideration of the nature, timing and intensity of interactions among factors and how they unfold over time. This is a challenge as cause and effect are often temporally separated due to system feedback, delays and accumulation processes (Sterman, 2000). There are no guidelines by which to judge the extent to which the nature, timing and intensity of interactions between factors actually drive the outcome of the competition. Inevitably this confounds the task of determining the relative influence of reinforcing and disrupting factors. More to the point, standards competition narratives are not tested to see: (i) whether they are internally coherent, (ii) whether the competition outcomes detailed in cases can really be an outcome of the proposed factor interactions and, (iii) how they measure up against other candidate explanations about the same competition outcome. Accomplishing this without simulation is difficult for three reasons.

First, the use of inductive methodology leads to a number of "if condition then competition outcome" statements that draw on competition cases and/or previous frameworks. This is the case in the framework of van de Kaa et al. (2011), where all of the 29 factors are distinguished depending on whether they have a reinforcing or abating effect and they are directly linked to format dominance, not to each other or other intermediate factors. For example, the accumulation of network externalities for one format confers a significant advantage to it and may lead to its dominance. But this is not enough. For example there may

be cases where what might appear as slow or no change, may be the result of opposing reinforcing effects from different factors. The converse is also possible i.e. abating interactions may be taking place but a standard may become dominant nevertheless. Therefore it is necessary to assess the intensity of interactions as well as their nature.

However, this is not enough either. The timing of interactions is important. Studying its effect requires that the influence of each factor on the outcome of competition is examined to deduce whether its timing really matters. For example assessing whether the effect of entry market timing is decisive or not, for the success of a format. Timing becomes even more important in cases of successive introduction of format generations as in the case of game consoles (Schilling, 1998). Nevertheless the outcome of the competition may be favourable or not, depending on other factors as well. Qualitative research may be sufficient for mapping system interactions and characterising their nature as reinforcing or disrupting, but not for evaluating the effect of their intensity and timing.

Second, the transient nature of format competition processes poses another limitation because all of the frameworks are developed drawing on completed competition cases. This is evidenced in the increase of format competition factors (van de Kaa et al., 2011). Thus the application of existing frameworks to future format cases should be made critically since the social and technological context has changed considerably and continues to change.

Addressing this point requires a systematic exploration of the influence that interactions among diverse factors and thus groups of stakeholders have in format competition in other words system boundary exploration. For example standard flexibility and its effect on attracting format supporter groups and increasing network diversity (van den Ende et al., 2012). Modelling a system mentally or digitally in order to study it always involves a judgement about system boundaries i.e. the range of potential causal factors involved given the temporal scale of the phenomenon. Since all boundaries are transient given enough time and complex systems are sensitive to small changes, boundary definition is important (Richardson,

2005). It reflects the assumptions made and the particular aims and needs of analysis, rather than the systems themselves (Cilliers, 1998). Varying assumptions about causal relations that are not well understood implies a corresponding variation of system boundaries and enables the construction of a range of possible candidate narratives about the same standards competition.

Simulation is an obvious tool with which to do this. In fact boundary adequacy testing is an integral part of system dynamics methodology (Sterman, 2000). Its process involves both searching for data in order to expand and explore the system boundary and the rigorous consideration of available data. Those that appear to be superfluous are removed and those that have some effect, even in contrast to the researcher's intuition, are included. This process transferred to format competition studies should result in a definitive set of influential factors and thus allow research to venture beyond identifying mere similarities among cases. Simulation models can serve as a mediating instrument between the real world and the highly abstract world of theory (Morgan and Morrison, 1999).

Third, some human cognitive limitations are inescapable even for researchers, specifically what has been identified as the "misperception of feedback" (Sterman, 1989a; 1989b) and the "stock and flow failure" (Cronin et al., 2009) according to which people do not appreciate correctly system delays, feedback and accumulation processes. This adds a further level of difficulty in updating the researcher's mental models about ongoing or completed format competitions. It is inevitably a long and ineffective process due to the causal ambiguity that path dependent systems exhibit when operating far from equilibrium (Sterman, 1994). Relying on empirical learning is slow and a limited amount is learned going around the loop each time, because (Meadows, 2008, p5): "systems happen all at once".

Furthermore, an important condition for effective learning about a phenomenon is that a time horizon greater than the delays embedded in the system is required. Subsequent to that, time is required to reflect and update the researcher's mental models about the system. There are two additional inherent limitations to this: (i) humans observe only one mode of system

behaviour, the one that actually takes place, and (ii) for processes that unfold over many years, it is difficult to update mental models in any meaningful way, simply because it is impossible to observe how the whole process unfolds.

The combination of qualitative analysis and a rigorous modelling and simulation methodology would increase the coherency of the format competition narratives with due attention to the richness of data. This is possible by linking case data collection to outlining the model system boundary and then using the latter to sift through available data and retain those essential for the competition mechanisms involved. One example of this approach using system dynamics is given in Schwaninger and Grosser (2008). The use of good modelling practice compels the researcher to specify the relationships between system elements and thus to construct transparent, parsimonious transition narratives. Modelling is like constructing haiku poems: small, concise and to the point, where "the art is in removing what you do not need" (Miller and Page, 2007, p42). Furthemore, following guidelines on communicating social science model results offer some reassurance that the integration of modelling and simulation communicate more of the logic behind the researcher's conclusions and thus it can be evaluated as to its contribution (Rahmandad and Sterman, 2012).

3. 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. Furethremore, 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 2 (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 2, *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 S*witching_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).

In Figure 3, 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 implies 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).

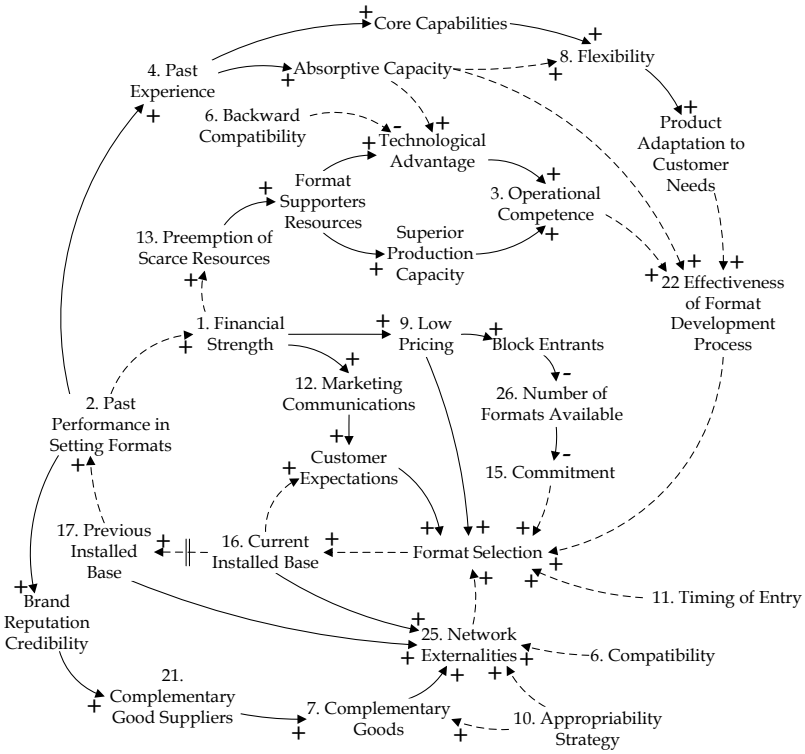

Figure 2 CLD: format supporter characteristics, format characteristics, support strategy

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 C*ommitment* 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.

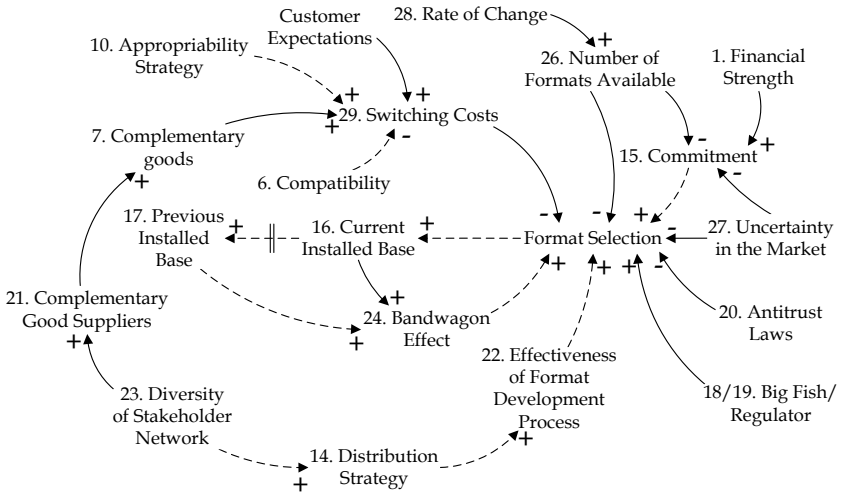

Figure 3 CLD of other stakeholders and market characteristics

4. A Model of Format Competition

A system dynamics model based on the CLDs discussed in section 3 and 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 Brunham 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_ξ is used that has a symmetric exponential distribution with parameter β and density given by:

$$f_\xi(x) = \frac{1}{2}\beta e^{-\beta x} \text{ for } x \geq 0 \quad (1)$$

$$f_\xi(x) = \frac{1}{2}\beta e^{\beta x} \text{ for } x < 0 \quad (2)$$

f_ξ has zero mean and variance $1/\beta^2$. 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_c has been formulated in the model as:

$$I_c(t) = U_s(t) \times (S_p(t) + S_f(t) + Sr(t)) \quad (2)$$

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

$$N_e(t) = P_b \times C_f \times CG(t) \times A_s \quad (3)$$

Where P_b is Previous Installed Base, C_f is Compatibility and A_s 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: $N_e(t) = CG(t) \times A_s$ (4)

5. 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 4 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.

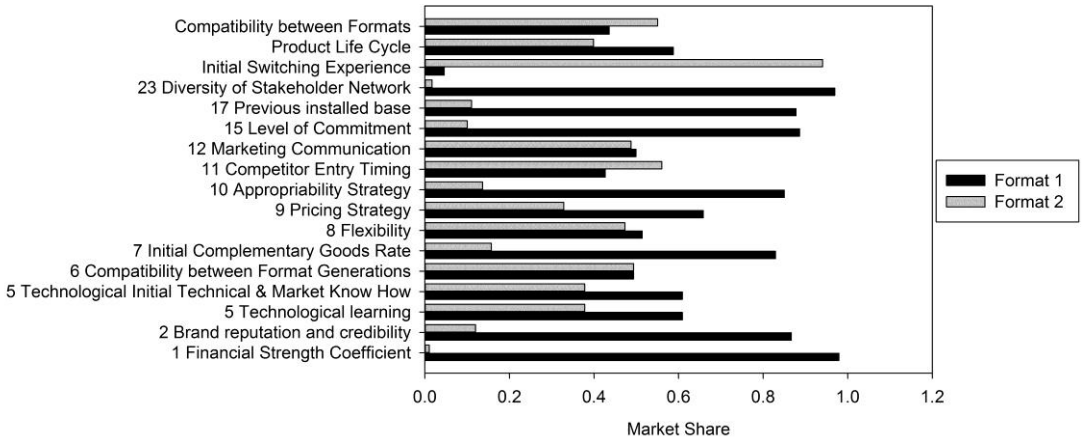

Figure 4 Test of deterministic factor influence on standard dominance

6. 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.

1. 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?
2. 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.

Case 1 simulation time	24 years	
Case 1 Factors	**Firewire**	**USB**
5 Technological superiority - learning	0.1	0.4
5 Technological superiority - Initial Technical & Market Know How	6	0.3
11 Competitor Entry Timing	1	7
15 Level of Commitment	0.1	0.6
Case 2 simulation time	**25 years**	
Case 2 Factors	**Wifi**	**HomeRF**
5 Technological Superiority Learning	0.2	0.1
5 Technological superiority - Initial Technical & Market Know How	0.4	0.3
11 Competitor Entry Timing	1	2
12 Marketing Communication	0.2	0.1
15 Level of Commitment	0.3	0.2
Case 3 simulation time	**24 years**	
Case 3 Factors	**MPEG**	**AC3**
2 Brand reputation - Past Performance in Setting Formats	0.2	1
5 Technological superiority learning	0.1	0.3
5 Technological superiority - Initial Technical & Market Know How	0.4	0.9
6 Compatibility between Format Generations	1	0.4
7 Initial Complementary Goods Rate	0.2	0.8
12 Marketing Communication	0.1	0.4
15 Level of Commitment	0.1	0.8
17 Previous installed base	12	0
Case simulation time	**13 years**	
Case 4 Factors	**Blu Ray**	**HD DVD**
2 Brand reputation - Past Performance in Setting Formats	1	0.4
15 Level of Commitment	0.6	0.3

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

Figure 5 on the left shows simulation results for the Firewire vs USB case. Due to the stochasticitiy 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 β 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).

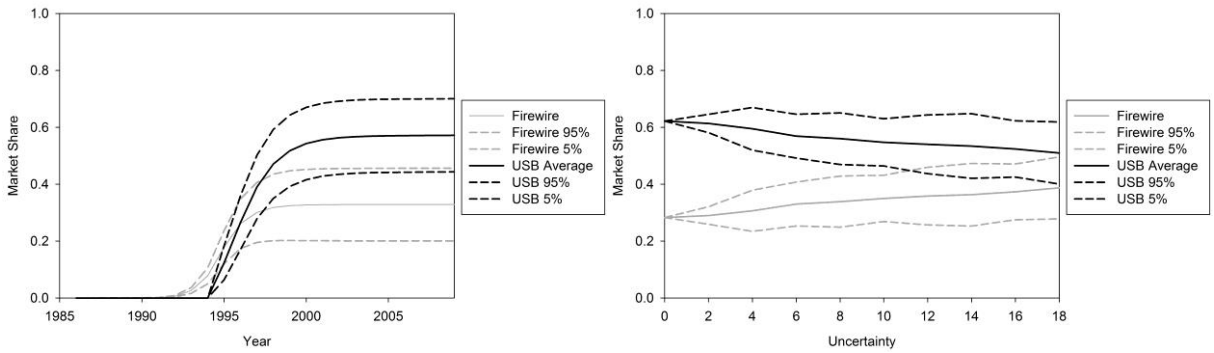

Figure 5 Simulation results from case 1: Firewire vs USB

Figure 6 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.

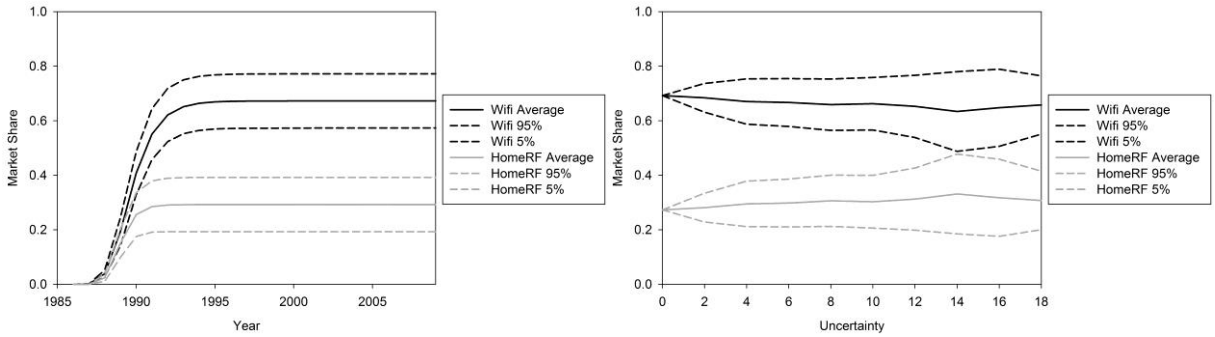

Figure 6 Simulation results from case 2: Wifi vs HomeRF

Figure 7 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 8 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.

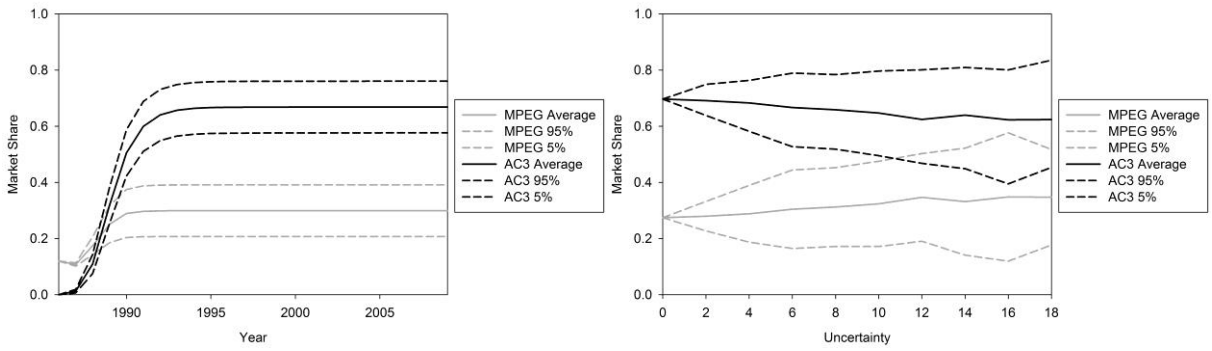

Figure 7 Simulation results from case 3: MPEG vs AC3

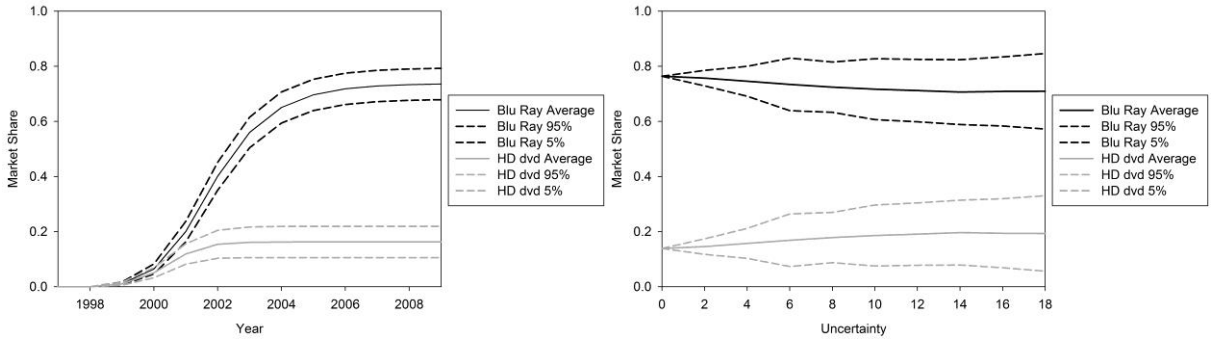

Figure 8 Simulation results from case 4: Blu Ray vs HD dvd

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.

7. 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 F_i has an advantage over F_j then sensitivity starts by setting $P_i = P_j$ 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 9). 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.

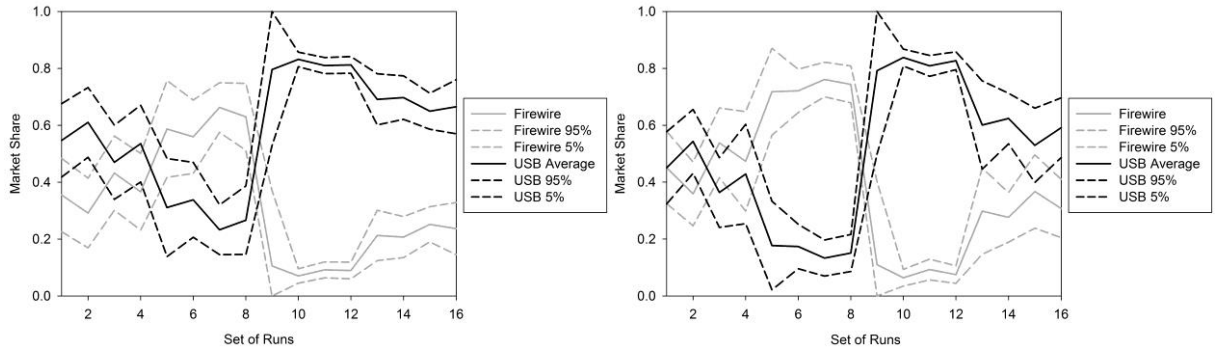

Figure 9 Sensitivity results from case 1: Firewire vs USB

Figure 10 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).

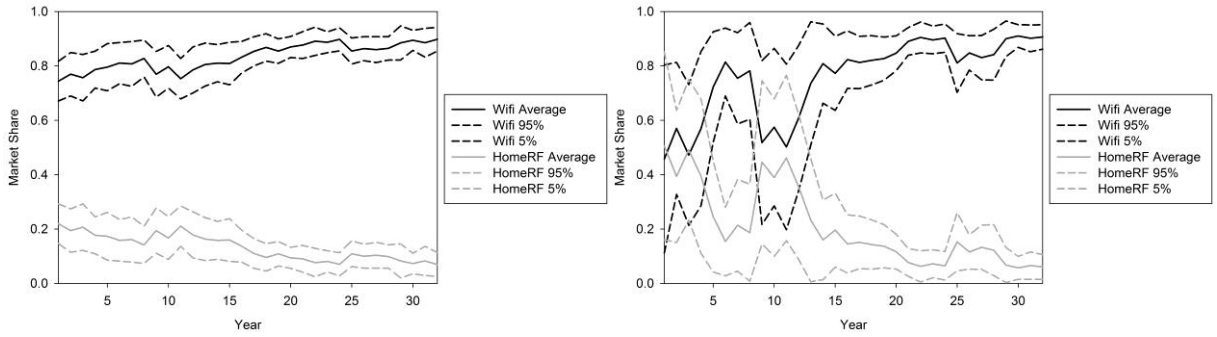

Figure 10 Sensitivity results from case 2: Wifi vs HomeRF

Figure 11 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.

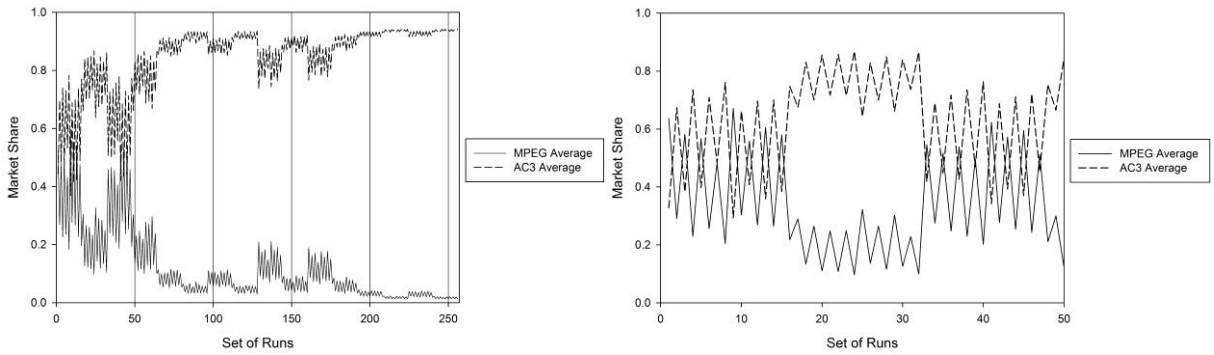

Figure 11 Sensitivity results from case 3: MPEG vs AC3

Figure 12 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.

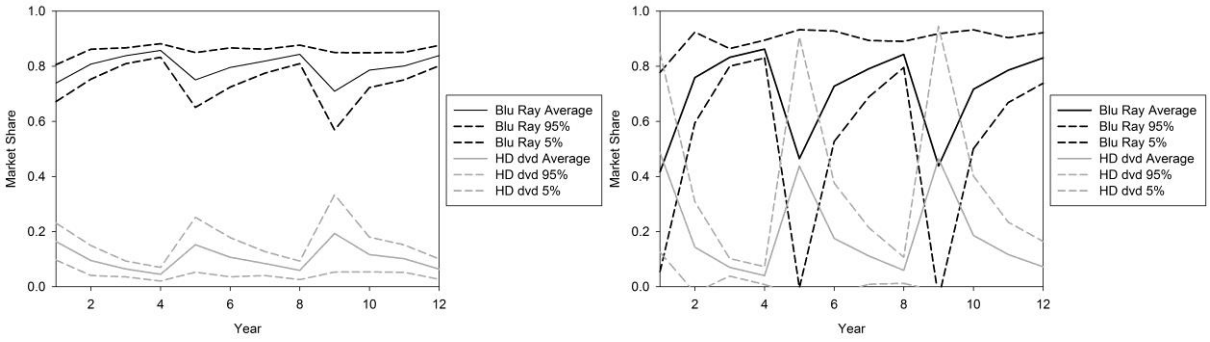

Figure 12 Sensitivity results from case 4: Blu Ray vs HD dvd

8. 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.

9. 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?

References

Adams, M., 1996. Norms, formats, rights. European Journal Political Economy. 12(2), 363-375.

Adler, S., 1992. The birth of a format. Journal of the American Society for Inion Science. 43(8), 556-558.

Adner, R., 2006. Match your innovation strategy to your innovation ecosystem. Harvard Business Review, 84(4), 98-107.

Papachristos, G., van de Kaa, G., 2014. Modelling Interface Standards Battles: A Retroductive System Dynamics Approach, 19th EURAS Annual Standardisation Conference, Belgrade, Serbia.

Archer, M., Bhaskar, R., Collier, C., Lawson, T., Norrie, A. , 1998. Critical Realism: Essential Readings, Routledge, London, UK.

Arthur, W.B., 1994. Increasing returns and path dependence in the economy. Michigan University Press.

Axelrod, R., Mitchell, W., Thomas, R.E., Bennett, D.S., Bruderer, E., 1995. Coalition ion in format-setting alliances. Management Science, 41(9), 1493–1508.

Barney, J., Clark, D.N., 2007. Resource-Based Theory: Creating and Sustaining Competitive Advantage. Oxford University Press, Oxford, UK.

Besen, S.M., Farrell, J., 1994. Choosing how to compete: strategies and tactics in formatization, Journal of Economic Perspectives, 8(2), 117-131.

Bhaskar, R., 1998. Philosophy and scientific realism. In: M. S. Archer, R. Bhaskar, A. Collier, T. Lawson, A. Norrie, (Eds.), Critical realism: Essential readings, Routledge, London.

Burnham, T.A., Frels, J.K., Mahajan, V., 2003. Consumer switching costs: A typology, antecedents and consequences. Academy of Marketing Science, 31(2), 109- 126

Christensen, C., Suarez, F.F., Utterback, J.M., 1998. Strategies for survival in fast-changing industries, Management Science, 44(12), S207–S220.

Cilliers, P., 1998. Complexity and Postmodernism—Understanding Complex Systems. Routledge, London.

Collier, A., 1994. Critical realism: An introduction to the philosophy of Roy Bhaskar. Verson, London.

Cronin, M., Gonzalez, C., Sterman, J.D., 2009. Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. Organizational Behavior and Human Decision Processes 108(1), 116–130.

David, P.A., 1985. Clio and the economics of QWERTY, American Economics Review, 75(2), 332–337.

Davis, J.P., Eisenhardt, K.M., Bingham, C.B., 2007. Developing theory through simulation methods. Academy of Management Review, 32(2), 480-499.

Egyedi, T.M., Blind, K., 2008. The Dynamics of Formats, Edward Elgar Publishing, Cheltenham, UK/Northampton, MA, USA, 2008.

Van den Ende, J., van de Kaa, G., den Uijl, S. de Vries, H.J., 2012. The paradox of format flexibility: The effects of co-evolution between format and interorganizational network. Organization Studies. 33, 705 – 736

Farrell, J., Saloner, G., 1986. Installed base and compatibility: innovation, product preannouncements, and predation, American Economic Review, 76(5), 940–955.

Garud, R., Karnoe, P. (Eds), 2001. Path dependence and creation. Lawrence Erlbaum Associates, London, UK.

Greenstein, S.M., 1993. Did installed base give an incumbent any (measurable) advantages in federal computer procurement? Rand Journal of Economics, 24(1), 19–39.

Hanseth, O., Monteiro, E., Hatling, M., 1996. Developing inion infrastructure: the tension between formatization and flexibility, Science Technology Human Values, 21(4), 407–426.

Hax, A.C., Wilde, D.L., 1999. The delta model: adaptive management for a changing world, MIT Sloan Management Review, 11–28.

Katz, M.L., Shapiro, C., 1985. Network externalities, competition and compatibility. American Economic Review 75(3), 424 – 440.

Katz, M.L., Shapiro, C., 1986. Technology adoption in the presence of network externalities. Journal of Political Economy 94(4), 822 – 841.

Kristiansen, E.G., 1998. R&D in the presence of network externalities: timing and compatibility, Rand Journal of Economics, 29(3), 531–547.

Lee, J., Lee, J., Lee, H., 2003. Exploration and exploitation in the presence of network externalities, Management Science, 49(4), 553–570.

Lee, J., O'Neal, D.E., Pruett, M.W., Thomas, H., 1995. Planning for dominance: a strategic perspective on the emergence of a dominant design, R&D Management, 25(1), 3–15.

Lehr, W., 1992. Formatization: understanding the process. Journal of the American Society for Inion Science, 43(8), 550–555.

Leiponen, A.E., 2008. Competing through cooperation: the organization of format setting in wireless telecommunications. Management Science, 54(11), 1904–1919.

Lieberman, M.B., Montgomery, D.B., 1988. First mover advantages. Strategic Management Journal, 9, 41–58.

Loch, C.H., Huberman, B.A., 1999. A punctuated equilibrium model of technology diffusion. Management Science, 54(2), 160 – 177

Meadows D.H., 2008. Thinking in Systems: A primer. Chelsea Green Publishing.

Miller H.J., Page E. S., 2007, Complex Adaptive Systems: An introduction to computational models of social life. Princeton University Press, New Jersey, US.

Morgan, M., Morrison, M., 1999. Models as mediating instrument. in Morgan, M., Morrison, M. (eds), Models as Mediators, Cambridge University Press, Cambridge, UK.

Oreskes, N., Shrader-Frechette, K., Belitz, K., 1994. Verification, validation and confirmation of numerical models in the earth sciences. Science 263(5147), 641 – 646.

Papachristos, G., van de Kaa, G., 2014. Factors for winning battles: A system dynamics modelling approach. 32nd International System Dynamics Conference, Delft, Netherlands, online proceedings

Rahmandad, H., Sterman, J.D., 2012. Reporting guidelines for simulation based research in social sciences. System Dynamics Review 28(4), 396 – 411.

Randers, J., 1973. Conceptualizing dynamic models of social systems: Lessons from a study of social change, PhD thesis, MIT, US.

Richardson, G.P., 2011. Reflections on the foundations of system dynamics. System Dynamics Review 27(3), 219 – 243.

Richardson, K., 2005. The hegemony of the physical sciences: an exploration in complexity thinking, Futures 37, 615 – 653.

Sayer, A., 1992. Method in social science: A realist approach, Routledge, UK.

Schilling, M.A., 1998. Technological lockout: an integrative model of the economic and strategic factors driving technology success and failure. Academy of Management Review, 23(2), 267–284.

Schmidt, S.K., Werle, R., 1998. Co-ordinating Technology. Studies in the International Formatization of Telecommunications. MIT Press, Cambridge.

Schwaninger, M., Grosser, S., 2008. System dynamics as model based theory building, System Dynamics Review 25, 447 – 465.

Shapiro, C., Varian, H.R., 1999. Inion Rules, a Strategic Guide to the Network Economy, Harvard Business School Press, Boston, Massachusetts.

Smit, F.C., Pistorius, C.W.I., 1998. Implications of the dominant design in electronic initiation systems in the South African mining industry. Technology Forecasting Social Change, 59(3), 255–274.

Sterman, J.D., 2000. Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin McGraw-Hill, New York.

Sterman, J.D., 1989a. Misperceptions of feedback in dynamic decision making. Organizational Behaviour and Human Decision Processes 43(3), 301 – 335.

Sterman, J.D., 1989b. Modelling managerial behaviour: Misperceptions of feedback in a dynamic decision making experiment, Management Science 35(3), 321 – 339.

Sterman, J.D., 1994. Learning in and about complex systems. System Dynamics Review 10, 291 – 330.

Suarez, F.F., Utterback, J.M., 1995. Dominant designs and the survival of firms. Strategic Management Journal, 16 (6), 415–430.

Suarez, F.F., Lanzolla, G., 2005. The half-truth of first-mover advantage. Harvard Business Review, 83(4), 121–127.

Suarez, F.F., 2004. Battles for technological dominance: an integrative framework. Research Policy, 33(2), 271-286.

Teece, D.J., 1986. Profiting from technological innovation: implications for integration, collaboration, licensing, and public policy, Research Policy, 15(6), 285–305.

Thomke, S., 1997. The role of flexibility in the development of new products: an empirical study, Research Policy, 26(1), 105–119.

Tripsas, M., 1997. Unraveling the process of creative destruction: complementary assets and incumbent survival in the typesetter industry, Strategic Management Journal. 18 (special issue) S119–S142.

De Vries, H.J., 1999. Formatization, a Business Approach to the Role of National Formatization Organizations, Kluwer Academic Publishers, Boston/Dordrecht/London.

Van de Kaa, G., 2009. Standards battles for complex systems: Empirical research on the home network. PhD thesis, Erasmus Research Institute of Management, The Netherlands, No. EPS-2009-166-LIS

Van de Kaa, G., van den Ende, J., de Vries, H., van Heck, E., 2011. Factors for winning interface battles: A review and synthesis. Technological Forecasting and Social Change, 78, 1387-1411

Van de Kaa, G., de Vries, H., van den Ende, J., 2013. Strategies in network industries: the importance of inter-organizational networks, complementary goods, and commitment. IAMOT conference proceedings

Van de Kaa, G., de Vries, H.J., 2014. Factors for winning battles: A comparative case study. Technological Forecasting and Social Change, in press.

Weick, K.E., 1989. Theory construction as disciplined imagination. Academy of Management Review 14(4), 516 – 531.

Willard, G.E., Cooper, A.C., 1985. Survivors of industry shake-outs: the case of the U.S. color television set industry, Strategic Management Journal, 6(4), 299–318.

Wonglimpiyarat, J., 2005. Format competition: is collaborative strategy necessary in shaping the smart card market?. Technological Forecasting Societal Change, 72(8), 1001–1010.

Wuisman, J.J.J.M., 2005. The logic of scientific discovery in critical realist social scientific research, Journal of Critical Realism, 4(2), 366-394.