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A Diagnostic for Lock-in*

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Abstract

In the context of increasing returns markets, the conventional argument is that a slender market share advantage may entrain a firm on a trajectory bound for monopoly in the long run. We revisit this with the linear urn model representation of history dependence, and a probabilistic characterization of eventual dominance. It is possible to explore the implications of varying the strength of feedback with a simple Pólya-urn scheme. It is then possible to determine how much stronger the positive feedback needs to be, in order to compensate for smaller initial market share of a firm, in attaining any specified degree of dominance. This allows us to place bounds on the probability that a firm will come to dominate an increasing returns market in the long run.

Keywords: Tipping, Lock-in, Dominance, Positive Feedback, Pólya's Urn, Initial Asymmetry, Feedback strength

JEL Classification: O33, L11, M30, C46,

1 Introduction

Many dynamic processes in the social and in the economic domains have the fundamental character of potential epidemics; for example, the diffusion of a technological innovation

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among a population of firms. The adoption process may *not* develop into a contagion; but under specific conditions the process is likely to *tip*, with an accelerating, if noisy increase in the share of adopters over a short duration[1]. The specific conditions mentioned above are those that generate positive feedback. The history dependence paradigm applies to such dynamic processes. Generally systems marked by positive feedback have multiple equilibria, and the equilibrium actually reached depends on initial conditions as well as transitory incidents in the process of getting there. Examples include the diffusion of standards, innovations and ideas, geographical agglomeration, and the evolution of market shares.

Network externalities (each customer gains more value, the more others are expected to make the same choice, and therefore tends to make her choice to accord with the choice made by other consumers) is one reason for positive feedback. Katz and Shapiro (1985, 1986, and 1994) show how incompatibilities between different product varieties can lead to the market tipping towards the dominant producer, causing its market share to expand due to consumer benefits driven by this producer's increasing dominance. There are other causes of positive feedback: word-of-mouth publicity, cost-advantages of larger scales of operation, and learning economies. In all of these cases, small and insignificant events early on in the history of the process can be decisive in selecting the end state. An outcome of a type in any period increases the probability of the same outcome type in the next period.

The most often recounted accounts of tipping and lock-in are of *inefficient* standards and technologies emerging dominant, starting from a competitive milieu. A classic example is the battle between QWERTY and DVORAK keyboard formats and the learning-by-doing and learning-by-using economies (David,1985). Among other examples there is the rivalry between CP/M, DOS and Macintosh among operating systems, and between VHS and Betamax among video-recorder formats, which we examine in Section 5. Claims of inefficiency of eventual winners have been contested (Liebowitz and Margolis, 1999).

Arthur (1989, see also, Arthur, Ermoliev, Kaniovski,1983, 1986) is an influential model of such diffusion processes based on the central idea that even if a consumer intrinsically prefers one among many choices available, she may choose another due to the benefit flowing

[1] Tipping involves a nonlinear response to marginal changes in causal variables under particular conditions: small changes have little effect on the system until a critical mass is reached, and then a further small change tips the system, producing a large effect (Gladwell, 2000).

from conforming to the choice made by others. Arthur's model is a generalization of Pólya's urn and explains lock-in in terms of *non-linear* feedback driving adoption: above (below) some threshold market share, future adoption rate is greater (lesser) than present market share due to interdependencies between consumer preferences. A system of this type will be stable only with monopoly - one of the shares will converge to one and the others to zero.

This result is strong and of much interest, but a model that can also support outcomes other than monopoly will be more useful for a number of reasons. First, stable patterns of market sharing, with one dominant firm and a number of smaller firms, are arguably more common than strict monopoly even among markets characterized by network externalities[2]. We exploit the fact that weakening the non-linear feedback assumption to Pólya's original assumption of linear feedback (future adoption rate is equal to present market share) can explain a range of equilibrium outcomes that stop short of monopoly. Secondly, linear adoption propensity is the most conservative assumption that can be made about the nature of positive feedback and thus should provide the most conservative estimate of the probability of dominance that arises from positive feedback. Finally, in a variety of increasing returns situations, feedback may be positive but not very strong[3]. While very strong positive feedback may secure monopoly for a firm with a slender market share lead, in other cases, where one competitor has a large initial lead, it should not take as strong a positive feedback for her to eventually attain any specified degree of dominance, compared to the situation where she has a smaller lead in initial share. Market share advantage can be a valuable competitive asset to the firm in the presence of positive feedback. Consideration of the *trade-off* between market share advantage and feedback strength evidently requires a model where the competitive process does not invariably result in eventual monopoly. We show how the linear feedback model makes precise the way in which higher 'initial' market share compensates for lower feedback strength in leading to a specific degree of eventual dominance.

This is of practical interest. An explicit consideration of the trade-off will focus attention of firms aiming at long run dominance to the pay-off to competing for initial advantage, conditional on the strength of positive feedback. In markets with trade-off, the leading

[2] In the context of two-sided markets network effects (e.g., online auction sites) Ellison and Fudenberg (2006) note stable market sharing and present a model with this equilibrium.

[3] Kattuman (1998) presents an empirical case.

firm that seeks to secure eventual dominance, will have even greater incentive to boost its current market share through whatever means available as growth rate of the market declines. Regulators should find in this model a useful diagnostic tool for prediction of lock-in to dominance. In Section 2 we motivate the use of Pólya's linear urn process as a simple and natural model that represents history dependence [4]. Conventionally, lock-in has been defined with respect to monopoly. In Section 3 we relax this and define dominance in probability terms. Lock-in is said to occur when dominance of one of the competitors is assured with some high probability. In Section 4 we present the method of obtaining the trade-off of interest. We characterize lock-in to specific degrees of (eventual) dominance in terms of the trade-off between initial advantage (history) and feedback strength[5]. This is done by conditioning on a specified degree of dominance, and backing out process parameters to characterize the trade-off between *initial asymmetry* and *feedback strength.* Section 5 offers an empirical application of this analysis the battle between VHS and Betamax.

2 Pólya's Urn Model

Pólya's urn (Pólya, 1930; see Pemantle, 2006, for a recent survey of the family of urn models) provides the simplest natural generative model for a reinforced random processes. The classical Pólya model provides sufficient structure for our analysis of history dependence in a competitive system with feedback and random shocks. The process is based on an urn with balls in different colors, and a sampling and replacement policy: draw a ball from the urn, observe its color, return it to urn (sampling with replacement) along with $S > 0$ balls

[4] See Page (2006) for a general review of concepts relating to history dependence.

[5] Trade-offs involved in contagion have been characterized in settings that are not centered on competition. In epidemiology the family of SIR models (e.g., Kermack and McKendrick, 1927) compute the theoretical number of people infected with a contagious illness in a closed population over time. Tipping is defined in terms of the set of conditions under which the reproduction rate of an infection - the number of secondary infections caused by a single primary infection - exceeds one. Beyond this threshold the infection rate exceeds the rate at which the infected population recovers. The trade-off at the *tipping point* is easily defined once the reproduction rate is formally defined in terms of the relevant parameters. The epidemiological aspect of diffusion was brought to marketing by Bass (1969). In the Bass diffusion model the adoption of an innovation by any customer makes adoption by other customers more likely, through infective word-of-mouth spread of information. The original model has a monopolistic setting and suppresses competition, only characterizing conditions for contagion. A small literature that generalizes diffusion in competitive settings has focussed on determining explicit market share trajectories. See Savin and Velu (2006) for a review and a recent model.

of the same color. History dependence of the process is reflected in the way the distribution of the proportion of balls of different colors in the urn change over time, depending on the sequence of sampled ball types, and in turn on the replacement rule. Each equilibrium of this linear replacement rule Pólya process is a distribution over (market) shares, defined on the unit interval. The more general urn model, with a non-linear replacement rule reflecting non-linear feedback has fixed proportions, rather than distributions, as equilibria (Freedman, 1965; Johnson and Kotz, 1977).

2.1 Pólya's Result

The main idea can be reviewed with a model in which two firms compete. Consider an urn containing balls of two colors, say, black and white; representing a market with two competing firms. The initial numbers of balls of different color represent initial sizes of the two firms. The sampling and replacement process drives the stochastic evolution of the proportions of the different colors in the urn.

Let $n = \{0, 1, 2, \ldots\}$ index the rounds over which sampling (and replacement) occur. Let B_0 be the initial number of black balls in the urn (at $n = 0$), and W_0, likewise, the initial number of white balls. S (≥ 1) is the number of balls replaced according to the replacement rule. S measures the 'strength of feedback' and is independent of the color of the sampled ball (S is common to both competing firms). Let B_n be the number of black balls, and W_n be the number of white balls in the urn after n rounds ($B_0 < B_n \leq \infty$, $W_0 < W_n \leq \infty$). $P_n = B_n \diagup (B_n + W_n)$ is the proportion of black balls in the urn after round n. The initial share (dis)advantage is measured by $P_0 = B_0 \diagup (B_0 + W_0)$ .We focus on the limiting proportion of black balls, $P = \lim_{n \to \infty} P_n$. Let $F(P)$ denote the cumulative distribution of P. Pólya (1930) proved:

Proposition 1 *The random variables P_n converge almost surely to a limit P. The distribution of P is Beta(α, β) where $\alpha = B_0/S$ and $\beta = W_0/S$. When $\alpha = \beta = 1$ i.e., $B_0 = W_0 = S$, the limit variable P is uniform on the interval* $[0, 1]$.

It is a non-intuitive result that Pólya's urn has a random limiting market share (See also Freedman, 1965). Note also that if there is no initial asymmetry, the distribution of the share of each color is uniform on the unit interval; all proportions of black balls are equally likely, a special case of the *Beta* distribution.

Athreya and Karlin (1968) and Athreya (1969) show that the two color result above generalizes to the case with any number of colors, with the shares of colors in this generalized Pólya's urn following a generalized *Beta* distribution over the unit simplex.

The urn model offers a simple representation of consumer choice. Suppose products of competing firms offer, *a-priori*, the same return to all consumers. If there are increasing returns as discussed in section 1, then returns to any consumer will change along the time path of the choices made by the population of consumers. A consumer on the verge of making a choice will wish to know the returns differential (due to the externality) between choosing the product of one firm rather than that of the other[6]. The urn scheme is a simple model of bounded rational choice behavior by imperfectly informed consumers who make their choices by observing others.

2.2 Strength of feedback and Initial asymmetry in the urn process

The initial proportion of black balls, $B_0/(B_0 + W_0)$, measures the initial market share (dis)advantage of black.

The number of new balls returned each period according to the replacement policy, represents the strength of feedback. Recall that S can be interpreted in terms of the number of consumers who in each period follow the example of the one consumer who actively samples the market to make her choice. The different (integer) values of S induce different limiting distributions. There are a number of points worth noting:

First, S is constant over rounds, and hence the growth *rate* of the market declines continuously over time. Second, $S \geq 1$ models growth - the model does not apply to the cases of $S = 0$ (in which case $B_n = B_0$ and $W_n = W_0$ for all n) or $S < 0$, which would

[6] The urn model represents her as sampling from among others who have made their choices, to choose the same as the majority in her sample. For $n > 1$, let $B_{n+1} = B_n.1_{U_{n+1} \leq P_n}$ and $W_{n+1} = W_n.1_{U_{n+1} > P_n}$, where $1_{U_{n+1}}$ is an indicator function for the event of drawing the random variable U_{n+1} from the interval $[0, 1]$. $U_{n+1} < P_n$ is the event of drawing a black ball in round n. Uniform draws correspond to drawing a black ball with probability P_n, independent of past draws. This probability is generated by the random variable U_n, which is the only source of randomness in going from round n to round $n + 1$.

be a model of negative feedback. Third, S is common to both competing firms, i.e. it is independent of the color of the sampled ball. Finally and critically, the simple urn process permits either black, or white to grow by S in each round, but not both.

The fact that the urn process only permits one firm to grow in any round leads to two interpretations of S: it is the amount by which the market grows, and so is the numerator in estimating the growth rate of the market; it is the amount by which either firm can potentially grow, and so is the numerator in estimating potential firm growth rate. The interpretation determines the way results from the model are to be interpreted - Specifically, given initial conditions, the model can yield useful *bounds* to the probability of a firm reaching any specified level of eventual dominance.

In empirical applications, S can be reckoned in alternative ways in estimating the probability of each firm's eventual dominance. Looking forward from $n = 0$, as the potential change in size of either firm, S will have to be based on $\Delta B = (B_1 - B_0)$ and/or $\Delta W = (W_1 - W_0)$, neither of these negative. One possibility is to fix S as the *net* growth of the firm that grew more, $|\Delta B - \Delta W|$. *Netting out* in this way will be consistent with the urn model assumption that only one firm will grow in each round, with symmetric potential of the observed *net growth.* In this case the probability estimates are not biased in favour of predicting dominance - if ΔB and ΔW are not too different from each other, compared to the case when these are very different.

On the other hand if S is equated to ΔB, or to ΔW or to an average (or the minimum or the maximum) of the two, then in reckoning the potential change in size of a firm we ignore the fact that the other firm may also have grown in the same period. The parameters of the model are then biased in favour of predicting dominance of the firm being considered. This should, in general, yield a liberal estimate of probability of dominance.

In this paper we allow two ways of reckonings S: the potential growth of either firm is measured by $|\Delta B - \Delta W|$, as well as by the weighted average of ΔB and ΔW : $(\Delta B\ .\ (B_0/(B_0 + W_0)) + \Delta W$ With either way of measuring S, we normalize it with the total initial number of balls in the urn, and measure *feedback strength* as $S/(B_0 + W_0)$, and interpret it as the growth rate of the market[7]. Recall that from the vantage point of $n = 0$, the long term prediction of the

[7] It is equally the weighted average of the potential growth rates of the two firms-

model is based on the assumption that in absolute value S does not change henceforth.

2.3 Critique

The linear Pólya process is of course a highly restrictive Markovian model of history dependence. The probability of adding S balls of a particular color is linear in the current proportion of that color in the urn. Generalizations, where the linear urn function is varied to allow the probability of an addition to a color to be an arbitrary function of the proportion of all colors, and in addition, this urn function is allowed to vary in a structured way, with time have been explored by Hill, Lane and Sudderth (1980) and Arthur, Ermoliev, Kaniovski (1983, 1986). In that body of work, the strong law that characterizes lock-in to monopoly follows from the nature of the pay-off to decision makers and the resulting adoption behavior. The pay off at time t from each alternative, B and W is due to a component reflecting the decision maker's intrinsic preferences for B and for W regardless of the number of other adopters; and another component, increasing non-linearly in the number of adopters, that reflects increasing returns to adoption. This second component renders the probability of adding a color higher (resp. lower) than the proportion of that color in the urn, above (resp. below) some specific threshold of the share of that color. If neither alternative is intrinsically preferred to the other then the equilibrium is dynamically selected from among the fixed points of the non-linear urn function that maps current proportions to probabilities of adoption. When the stable fixed points of the non-linear urn function occur only at 0 and at 1, one of the firms will end up the monopolist. It is the non-linear form of the returns to adoption function that drives the convergence of the stochastic adoption process to total dominance by either B or W with probability 1[8].

In contrast, each equilibrium of the linear (returns to adoption such that the probability of adding a color is equal to the proportion of that color) Pólya process is a distribution over the unit interval - the range of market share. The parameters of the process - initial market share and feedback strength - can weight equilibrium distribution towards one way

$((S/B_0).(B_0/(B_0+W_0))+(S/W_0).(W_0/(B_0+W_0)))$

[8] Bassanini and Dosi (2006) show that this result depends on the nature of increasing returns with respect to the degree of heterogeneity of the population.

or the other, ranging from monopoly to one color, all the way to complete symmetry. The implication of the equilibrium being a distribution is that depending on initial conditions, the process could converge to *any* proportion of black balls.

As an aside, note that as the number of balls in the urn increases, the current proportion will grow more stable. Initially, each round of addition of S balls to the urn will have a large influence on the probability of choice of color of the next batch of S balls and market share changes will have a larger variance than in the non-linear model. Over time (as the total number of balls in the urn increases) the importance of positive feedback will decline. As mentioned earlier the market movement is ever towards saturation. Given initial conditions the linear Pólya process provides the conservative estimate of the probability of lock-in to any specified degree of dominance.

It is worth re-iterating the Markovian character of the linear process: for the outcome in round n, the sequence by which the numbers of black and white balls had accumulated by round $n-1$, to B_{n-1} and to W_{n-1}, does not matter. The long run equilibrium, looking forward from any round depends only on the set of outcomes that arose till that date, and not upon their order of occurrence. Independence of the equilibrium from the sequence makes it possible to obtain the (lower bound) probability of dominance in the long run, looking forward from any chosen date.

3 Lock-in

The notion of lock-in employed in this paper refers to a *producer* entering a trajectory leading to eventual dominance. This is directly related to the idea that costs of switching (either direct costs, or due to external increasing returns that flow from the value of the network of users of the product variety) to a new product variety or a new technology can lock a *consumer* into her current choice. The producer lock-in notion is also related to the idea of tipping - the epidemiological concept applicable to consumer behavior, that there may be a point in the trajectory where market share changes very rapidly. A market that has tipped will be locked-in, sustaining the dominance of the leader. But our focus in this paper is solely upon eventual dominance; we do not model transitory dynamics and do not offer any

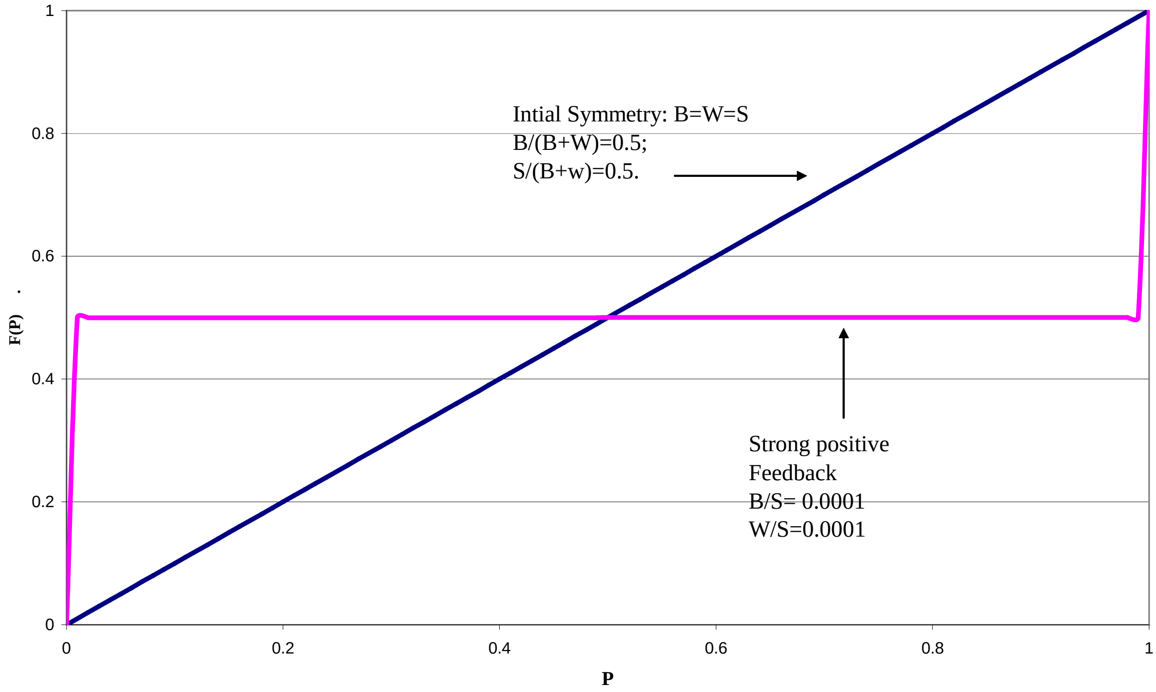

Figure 1: Polya Process: Asymptotic Distributions of Black Proportion - Extreme cases.

analysis of tipping.

Competition law is concerned with the abuse of 'dominant market position', which is conventionally defined in terms of market shares, for example, by the US Department of Justice, and in Article 82 of the EC treaty. The notion of *lock-in* to dominance relates to current conditions that lead to dominance in the long run. In conventional terms, lock-in to dominance (for black, say) can be said to have occurred at the point where the long-term forecast of the black market share equals 1:

$$\lim_{n\to\infty} E\left(\frac{B_n}{B_n+W_n}|\frac{S}{B_0+W_0},\frac{B_0}{B_0+W_0}\right)=1$$

This is the extreme case of lock-in, which as noted above, relates to a non-linear Pólya process with fixed points of the urn function at 0 and 1. Note however that in a linear Pólya process, high values of S, relative to B_0 and W_0, can make the limiting probability of monopoly arbitrarily close to 1, as Figure 1 illustrates.

A more general notion of dominance should permit us to relax the monopoly requirement, and label a market as locked-in, if a firm is on track to exceed some specified (high) share, with some stipulated probability. We now pin down this probabilistic notion of lock-in.

3.1 Probabilistic definition of Lock-in

When the equilibrium is a probability distribution over market share, dominance in the long run can be defined in terms of a threshold market share (that is sufficiently high - at least y %) and a probability (at least x %) that this share is exceeded in the long run. The analyst (or the competition authority) can choose the probability and market share thresholds at any value depending on what is appropriate for an application.

In this paper we define these thresholds from a statistical view point. We start by noting that when the urn process is marked by initial symmetry, i.e., $B_0 = W_0 = S$, the limiting distribution of the share of each color is uniform over the unit interval. On this basis, we may ask: what is the probability that the share of black will (eventually) exceed, say, 95%? Turning this around, we may start with a specific significance level, say 10%, and ask: what is the market share that the *largest* among the competitors will eventually exceed with *only* 10% probability if the urn process is initially symmetric? Thus we define the market share dominance threshold as the value that would be exceeded at some specific conventional significance level by the *largest* share when the share of each firm is drawn randomly from the uniform distribution. Other significance levels may be appropriate depending on context and how conservative we wish to be in defining dominance.

Fisher (1929) derived the distribution of the largest share when all shares are drawn uniformly from the unit interval. In the m color case, adopting the notation convention for order statistics, the CDF, $F()$, of the largest share denoted $P_{(1)}$ is given by:

$$1-F(P_{(1)}) = m\left(1-P_{(1)}\right)^{m-1} - \frac{m(m-1)}{2}\left(1-2P_{(1)}\right)^{m-1} + \ldots + (-1)^{k-1}\frac{m!}{k!(m-k)!}\left(1-kP_{(1)}\right)^{m-1}$$

where k is the smallest integer less than $1/P_{(1)}$. Specializing Fisher's distribution to two colors there is: 1% probability that the largest share is greater than 0.995; 5% probability that the largest share is greater than 0.975; and 10% probability that the largest share is greater than 0.95.

In summary, our probabilistic definition of lock-in is defined with reference to a level of significance. For example, given that under the uniform distribution of all shares, the largest single share will exceed 0.975 with 5% probability, the set of values of the parameter pair of the Pólya process that map to 5% probability that the limiting share of black is at least 0.975, define the set of initial conditions that lock-in the market to black dominance. The anchors of this definition of dominance are the significance level, and the random division of the unit interval that follows from the symmetric Pólya process.

In general terms, denoting the significance level for defining lock-in by ε, lock-in for a competitor can be said to occur for that level $(0 < \varepsilon < 1)$ if:

$$1 - \varepsilon = F(P)$$

4 The Trade-Off between Initial Asymmetry and Strength of Feedback

The trade-off is easily determined. Given $P \sim Beta(\alpha, \beta)$, where $\alpha = B_0/S$ and $\beta = W_0/S$, for the chosen level ε, we can solve $1 - \varepsilon = F(P)$ to find the set of values for the parameter pair $\{(\alpha(\varepsilon), \beta(\varepsilon))\}$. With reference to each element in this set we can determine the unique feedback strength: $S/(B_0 + W_0) = 1/(\alpha + \beta)$, required for each specified level of initial asymmetry: $B_0/(B_0 + W_0) = \alpha/(\alpha + \beta)$.

Figure 2 illustrates with two equilibria (distributions over market shares). The intersection point of the two distributions indicates that with both sets of initial conditions, the probability of limiting market share of black exceeding 0.80 is 40%. The infinite number of equilibria that pass through the point $(P, F(P))$, and the corresponding set of initial conditions characterize the trade-off of interest, which is conditioned on the specific degree of dominance.

Figure 3 presents an iso-dominance map. There is 20% probability that largest share will exceed 0.90 under random division of the unit interval into two shares. The curve at the left end in figure 3 presents the set of pairs $\{(B_0/S, W_0/S)\}$ such that the probability of

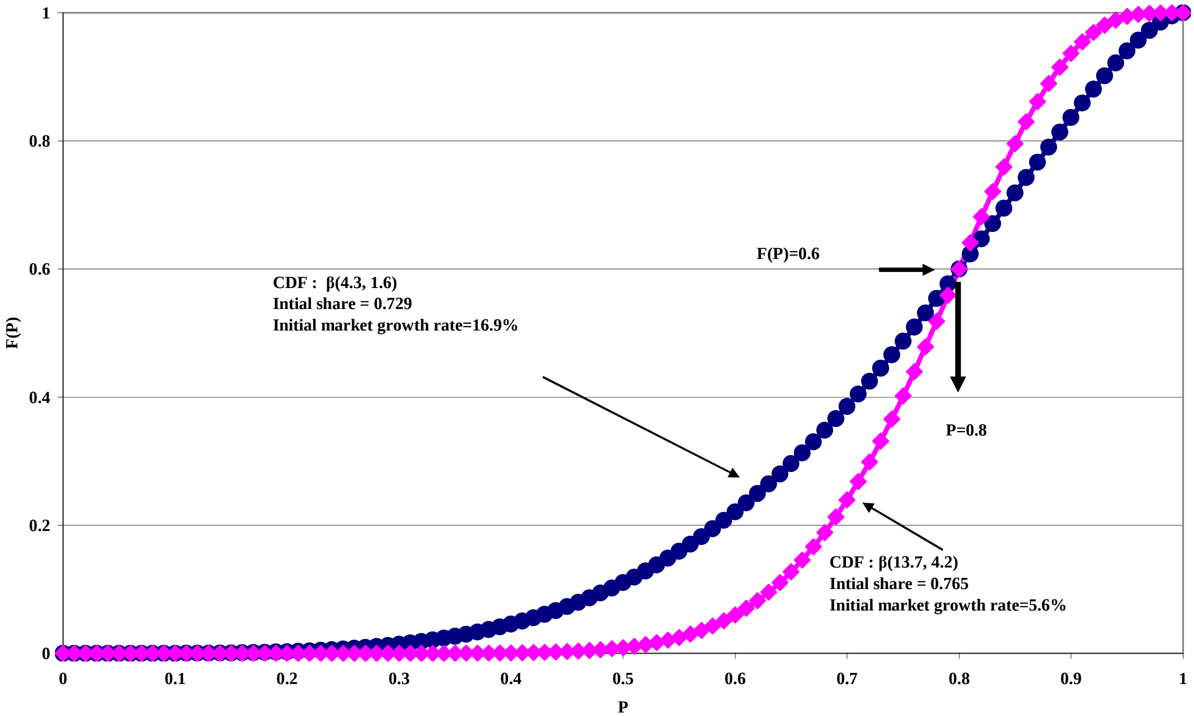

Figure 2: Asymptotic Distributions of the share of Black

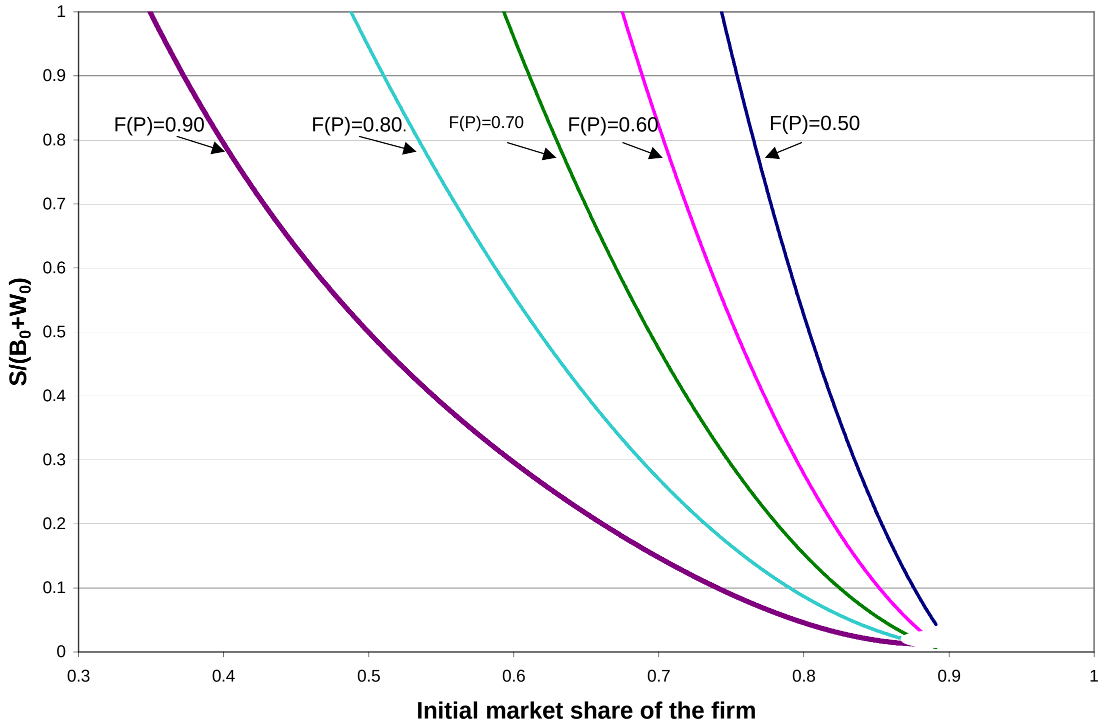

Figure 3: Iso-Dominance map: Probabilities of limiting market share of 0.90 or over

eventual market share exceeding 0.90 is 20%.This represents the variety of initial conditions and provide the trade-off between initial market share and market growth, conditioned on dominance defined with respect to a 20% significance level. The other iso-dominance curves in the figure correspond to other (probabilistically specified) levels of eventual dominance. For a given initial market share, higher degrees of eventual dominance requires higher rates of market growth. It is worth noting that there is some (high) market growth rate that can make the dominance of the firm with the smaller market share sufficiently likely. This follows from the fact that with probabilities equal to their market share, both firm grow by the same amount, S.

By averaging the dominance threshold growth rates of any market share and its complement in unity, it is straightforward to estimate the market growth rate such that the market will eventually come to be dominated by one firm *or* the other. In Figure 4, there is 10% probability of one firm or the other obtaining a market share of 0.90 (and thus of the market being dominated) if the current market growth rate is as given by the curve for the given

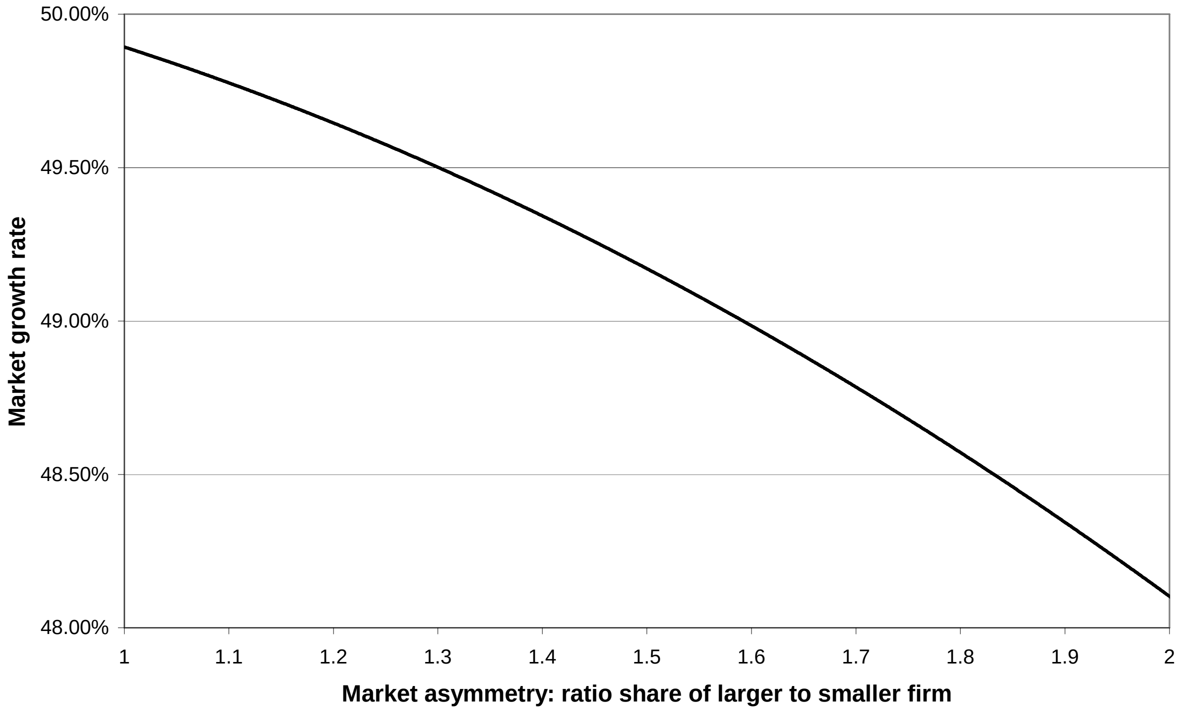

Figure 4: Asymmetry Vs. Growth: 10% probability that the market will eventually be dominated by some firm

asymmetry. The *required* market growth rate does not fall much with increasing asymmetry.

We now turn to an empirical application.

5 Application: VHS Vs. Betamax

There are many detailed accounts of the fight for dominance among different VCR formats; see Cusumano, Mylonadis and Rosenbloom (1992), Grindely (1992) and Liebowitz and Margolis (1994). In brief, Sony pioneered the commercialization of home video recording technology in 1975 with the Betamax system. Eighteen months later the VHS standard was launched by a consortium consisting of Matsushita, JVC, and RCA. Customers had to choose between the two as tapes and machines were not compatible between the two standards. By 1979 VHS had gained a market share lead over Betamax VHS continued to grow through the 80's, while Betamax shrank. By 1988 VHS was so dominant that Sony abandoned the Betamax standard.

We illustrate the trade-off between initial market share and feedback strength in the Videorecorder market. Using sales data from Cusumano *et al.* (1992) we estimate, for each year between 1977 and 1984, limiting probability distributions of market shares for both VHS and Betamax. For each year, the observed market shares and the yearly growth of the two standards provide the initial conditions (Figure 5). Note the high levels of market growth that were characteristic of the early years.

Until 1977 Betamax was a monopolist and it remained the market leader for another year. The urn model cannot explain market evolution looking ahead from either 1975 or 1976, when VHS had not yet entered the market; it requires all competitors to be present in the market, with non-zero market shares. Cusumano *et al.* (1992) provide an account of the entry strategy followed by JVC and Matsushita.

We bring the model into play from 1977 when both VHS and Betamax were in the market. The attractiveness of the different formats to the consumer depended, as with any product, on price and quality (picture clarity, programmability, ease of use, size etc.). When the focus is on positive feedback, the absence of compatibility is the key factor. As the installed base of VHS format machines increased, so did its attractiveness to potential buyers, and this in turn increased market share, boosting installed base further. Complementary assets: rental stores choosing to stock tapes in the more common format, and studios offering films in the format compatible with the more popular technology were also sources of positive feedback.

Figure 6 presents the iso-dominance curve illustrating the trade-off between observed (initial) market share and feedback strength derived from the linear Pólya process. Dominance is defined at the level of a limiting market share threshold of 0.95 with 10% probability. Each year, one can look ahead to the long term prospects of both VHS and Betamax, judging them against the dominance threshold.

S has been reckoned in two ways. S defined as $|\Delta VHS - \Delta Betamax|$ gives us a (generally) conservative estimate of the growth opportunity for a firm, in so far as it allocates only *net* growth to the firm that has grown more. S defined as the weighted average of ΔVHS and $\Delta Betamax$ give us a (generally) liberal estimate of the growth potential for a

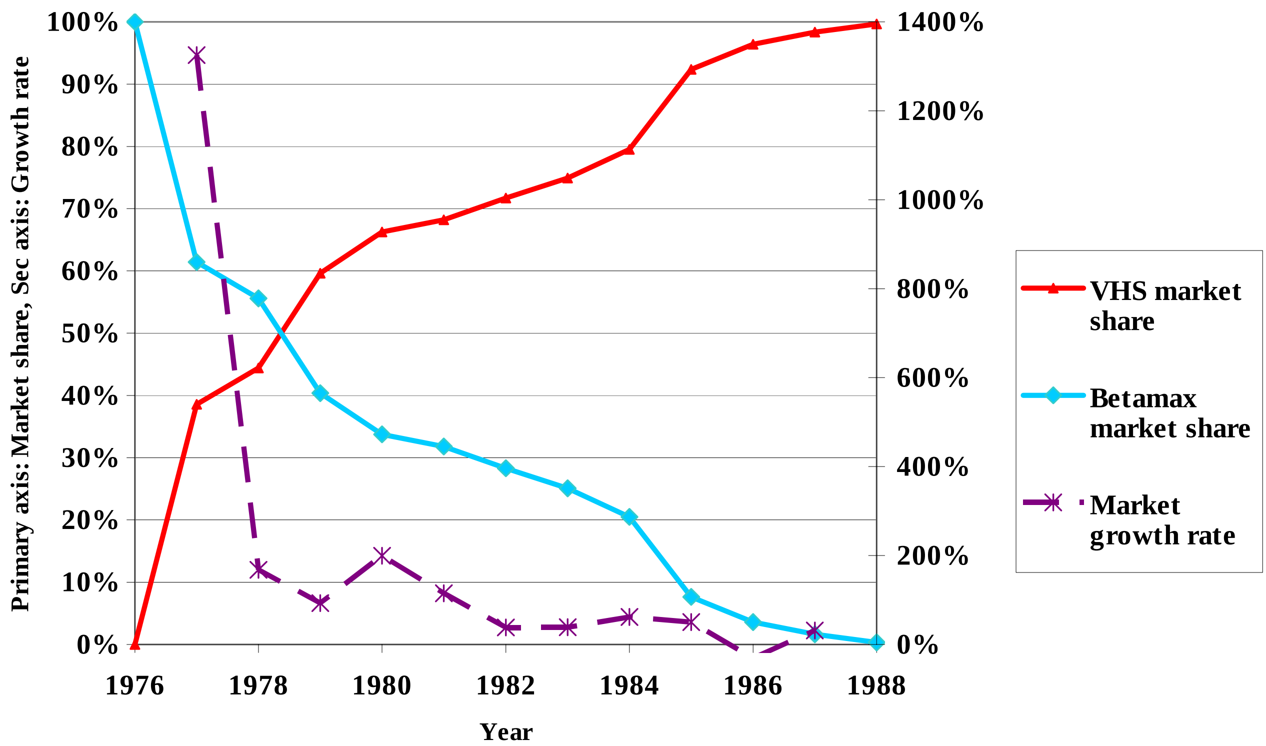

Figure 5: VHS and Betamax market shares and VCR market growth rate, 1976 to 1988

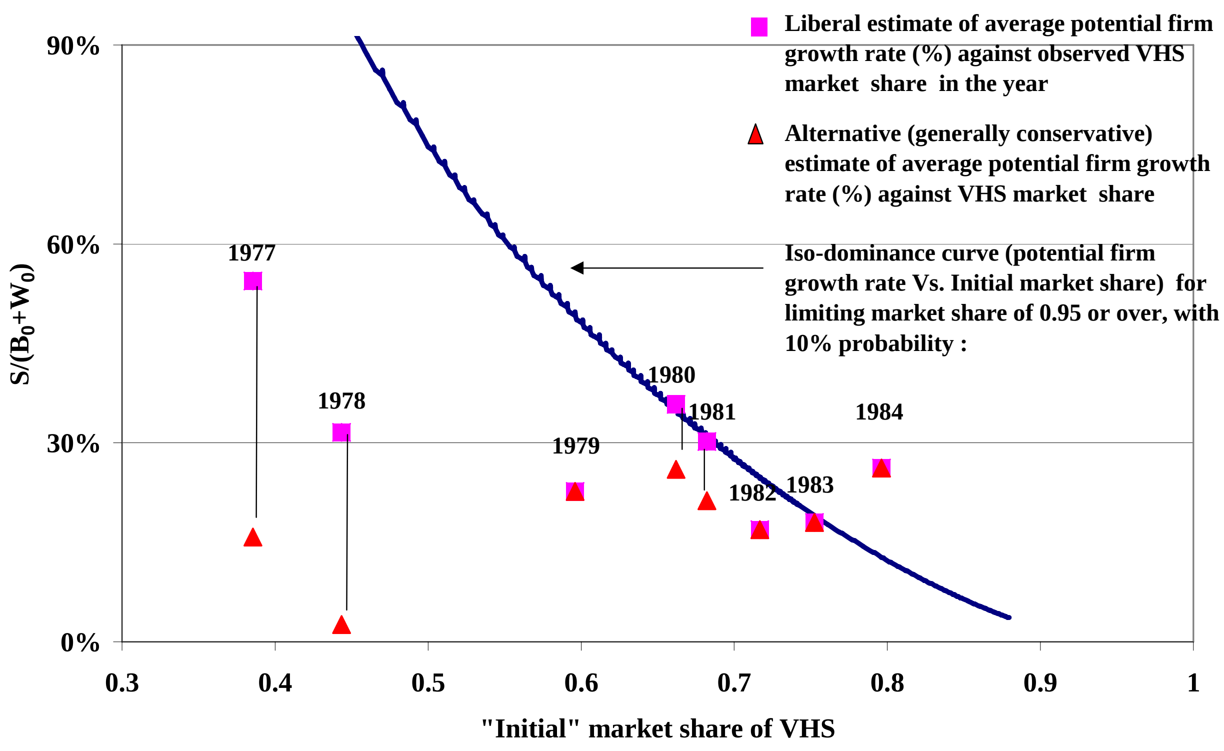

Figure 6: Iso-Dominance Threshold: 10% Probability that limiting share is 0.95 or over

firm in that it ignores the fact that the other firm is also growing. $S/(VHS_0 + Betamax_0)$ measures *feedback strength,* and the alternative ways in which S is reckoned gives us the lower and upper bounds on the growth rate of the firm.

Figures 7 and 8 present the estimated lower and upper bounds to the probability that the long run market share of VHS and of Betamax will exceed 0.95, for each year between 1977and 1984, conditioned on asymmetry between market shares and feedback strength (which reflects overall market growth) observed that year. Betamax was the market leader in 1976, and this combined with the high rate of growth of the market to 1977, gave the company a significant probability (13%) of eventual dominance, by the liberal reckoning (Figure 8). Even though VHS was much the smaller player (market share of 0.39) in 1977, the growth rate of the VCR market secured for it 2% probability of a limiting market share of 95% or greater. The decline in market growth between 1977 and 1978 reduced both firms' prospects of dominance. The probability of Betamax dominance fell virtually to zero

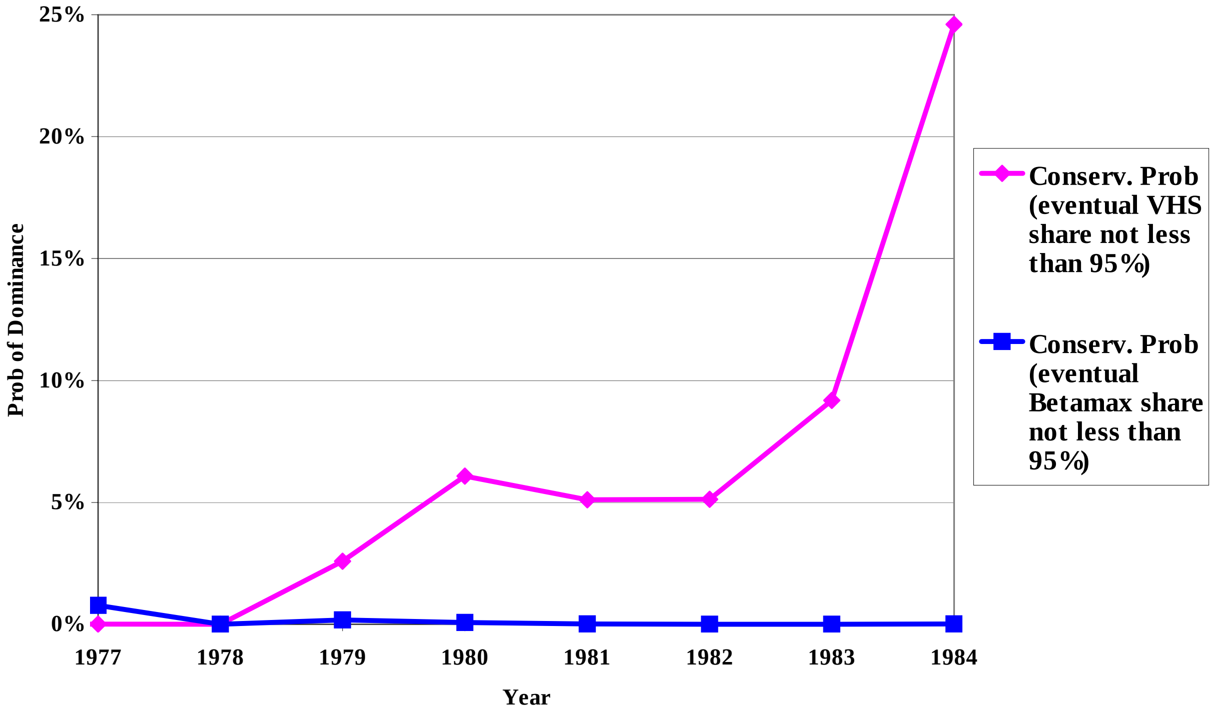

Figure 7: Lower bound to probability of Dominance (limiting market share not less than 95%)

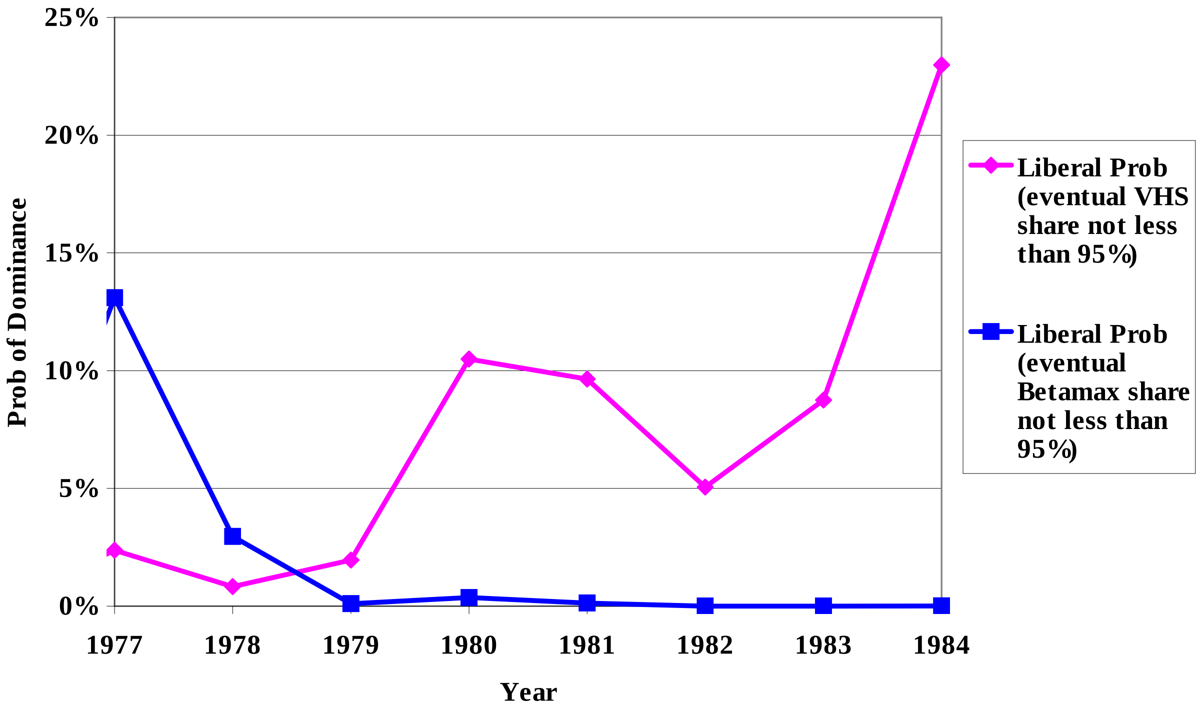

Figure 8: Upper bound to probability of Dominance (limiting market share not less than 95%)

by 1979, even though Betamax had a market share of 0.32 that year. The growth of the market between 1979 and 1980 and the increased share of VHS which overtook Betamax in this period, combined to increase the probability of VHS dominance sharply. The effect of the decline in market growth between 1980 and 1982 was clearly to diminish the prospect of VHS dominance even though its market share continued to rise. Between 1982 and 1984, the market growth remained steady, but the increased market share of VHS again enhanced the likelihood of VHS dominance.

6 Conclusions

The idea that market share can be a source of competitive advantage in the presence of increasing returns can be traced all the way back to Adam Smith, and runs through a lineage that links Marshall, economic geographers, and economists who in the 80s began to develop decision theory based models of increasing returns.

In this paper we present a method for determining the probability that a competitor will come to dominate a market that is characterized by positive feedback. Feedback, often traced back to increasing returns, is a self-organizational feature in a large class of markets and systems. Looking to such markets we represent market dynamics using a simple linear urn process, instead of the now conventional non-linear urn process associated with Arthur, Ermoliev and Kaniovski. This, combined with a probabilistic definition of the notion of lock-in to dominance makes it possible to determine, for any defined degree of dominance, the trade-off between initial conditions - between initial market share denoting initial (dis)advantage on the one hand, and on the other, feedback strength which is related to potential firm growth in the market.

It is clear that the prospect of dominance depends on the interplay of growth of the market and market share advantage. When a market is characterized by positive feedback, the likelihood of dominance is enhanced in a natural way by market share advantage if the market is growing. A decline in the rate of growth of the market reduces the prospect of dominance of both the market share leader as well as the follower. It takes progressively greater current share advantage to compensate for successive declines in the rate of growth of the market. Thus, while dominance is to be expected in growing, increasing returns markets, the dominant firm can also be expected to have greater incentive to erect barriers to the growth of rivals (for example, through pricing and advertising) in slower growing markets or periods. This is different from the case of finely poised markets with non-linear feedback that are prone to tip and lock-in to monopoly, where competition will be particularly intense early on.

It must be admitted that this analysis is concerned only with the long run. The time frame in which dominance is achieved, as well as transient market share dynamics will matter to firms, but is not considered by this analysis. But forecasting eventual winners in dynamic competition is a sufficiently difficult art in itself. The application of the method to the battle between VHS and Betamax in the Videorecorder market illustrates its empirical potential.

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