STRATEGIC MANEUVERING AND STANDARDIZATION: CRITICAL ADVANTAGE OR CRITICAL MASS?

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February 2004

It is widely speculated that the adoption of a technology takes off to be self-sustaining if it reaches the critical mass. However, the sponsors of competing technologies may engage in strategic maneuvering in the adoption process. Indeed, this paper shows that in the de facto standardization process of the U.S. home VCR market, there was strategic maneuvering by the Betamax sponsor, which created only temporary interruptions. The counterfactual simulations, however, indicate that there is no irreversible critical mass and the sponsor of Betamax could reverse the tipping process if it had a critical strategic advantage which is determined by the difference in installed bases and other factors of consumer expectations for future adoption rates.

KEYWORDS: network externalities; de facto standardization; strategic maneuvering; critical advantage; VCR.

JEL Classification: L15; L11; L68.

* I am grateful for the comments from the participants of the 3rd IEEE Conference on Standardization and Innovation in Information Technology. All errors and omissions are my own.

1. Introduction

Since the study by David (1985) of the adoption of the QWERTY typewriter keyboard, the possible lock-in to inferior technology by historical accidents has attracted economists' attentions.[1] Arthur (1989), based on a simple non-strategic (or biological) model, demonstrates that *random* historical (small) events may lead to this type of lock-in with the existence of increasing returns to adoption. Network externalities, which are usually understood as positive consumption externalities, have been considered a source of these increasing returns to adoption.[2] The recent empirical study of Park (forthcoming(a)), based on a structural model of dynamic oligopoly, provides a dynamics of de facto standardization in the presence of network externalities.[3] This dynamics is called an *amplification-reinforcement process* and indicates that the small difference in the *initial* installed bases, which were accumulated prior to the network externalities in action (via the consumer's use of prerecorded videocassettes such as movie titles), amplified the difference in sales between VHS and Betamax via network externalities, leading to a bigger advantage with more installed bases. Moreover, this amplification-reinforcement process in the presence of network externalities was reinforced by the expected future dominance of VHS, and this expectation itself became the main reason for the network advantage of VHS in the early stage of competition.

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[1] Some researchers argue that the QWERTY typewriter keyboard was not inferior. See Liebowitz and Margolis (1990).

[2] In general, network externalities are categorized as either direct or indirect. In the presence of (direct or indirect) network externalities, an increase in the users of a product raises the consumer's utility level and hence the demands for that product directly (as in the case of fax machines) or indirectly (via an increased variety of available movie titles as in the case of VCRs). In the literature of network externalities, the number of users is called a network size, and the user's benefit from the network size is called a network benefit. Refer to Katz and Shapiro (1994) and Park (forthcoming(c)) for the literature review and the recent issues.

[3] Previous theoretical studies have focused on the consumers' adoption decision of new technology over old technology (Farrell and Saloner, 1986; Choi, 1994) or producers' introduction timing and compatibility decision of new technology (Katz and Shapiro, 1992; Kristiansen, 1998) in the presence of network externalities.

Apparently, this interpretation of Park (forthcoming(a)) is consistent with the popular idea of the *critical mass*: the adoption of a technology with network externalities takes off to be self-sustaining if it reaches the critical mass (see, for example, Allen, 1987; Economides and Himmelberg, 1995; Lim, Choi and Park, 2003; Mahler and Rogers, 1999; Markus, 1987). However, extending the results in Park (forthcoming(a)), this paper will highlight two very important factors in the technology adoption process, i.e., *strategic maneuvering* and *consumer expectations* for future adoption rates, which have not been explicitly analyzed in the typical diffusion models (see Allen, 1987; Economides and Himmelberg, 1995; Lim, Choi, and Park, 2003; Mahler and Rogers, 1999; Markus, 1987; Saloner and Shepard, 1995).

In contrast to the model in Arthur (1989), technologies are typically sponsored by firms which engage in strategic maneuvering in the adoption process.[4] In fact, there was strategic maneuvering (in price and product quality) of Betamax, which created only a temporary interruption of the tipping and de facto standardization process toward the VHS format. In the paper, based on counterfactual simulations of the U.S. home VCR market during the years 1981 – 1988, we study the dynamics between the network externalities and the strategic advantages (in price and quality) in the process of de facto standardization. The counterfactual simulations will indicate that there is no *irreversible* critical mass and the sponsor of a technology can reverse the tipping process if it has a sufficient strategic advantage in price and/or product quality which is called the *critical advantage*. The critical advantage, however, is not an absolute amount of strategic advantages but depends on the difference in installed bases and the other market conditions which affect consumer expectations for future adoption rates. In addition, it will be shown that the difference in installed bases (or seemingly the critical mass) is not a trigger but an amplifier-and-reinforcer of the bandwagon effect in the presence of network externalities.[5]

[4] For instance, the two competing technologies in the home VCR market (the Betamax format and the VHS format) were sponsored by Sony and Matsushita, respectively. Katz and Shapiro (1986) shows that the pattern of adoption depends on whether technologies are sponsored or not.
[5] The initial installed bases can be a critical advantage in as in the case of the U.S. home VCR market.

The counterfactual simulations of this paper are based on the structural demand function in the market for newly introduced durable products with network externalities. Instead of fully calibrating the structural model in Park (forthcoming(a)) and the equilibrium behavior of entry and exit, we will decompose (the logarithm of) the relative sales of two competing technologies (the Betamax and the VHS formats) into the advantage in network effects, the strategic advantage in price and quality, and the lineup advantages. Since we are mainly interested in the effects of strategic advantages in price and product quality on the de facto standardization process, the strategic advantage is considered a control variable in our simulations.[6] Note that the effects of consumer expectations for adoption rates are reflected in the network advantages since the network effect is the average network benefit (in the current and future periods) projected by current available information. The lineup advantage of VHS was generated by the licensing agreements between the sponsors and the licensees which allow entry into the VHS lineup and the exit from the Betamax lineup. However, the reason that the more producers (or licensees) have positive effects on the format sales is consumers' preferences for the variety of the products. Hence, the lineup advantage reflects that the sponsor can amplify the relative sales, if its technology is more advantageous, via licensing for product differentiation. Then, with further calibrations on the advantage in network effects and the lineup advantage, we can directly calculate the impacts of strategic advantages on the dynamics of the competing technologies.

The organization of the paper is as follows. Section 2 will briefly review the results in Park (forthcoming(a)) and proceeds further to discuss strategic maneuvering in the de facto standardization process of the U.S. home VCR market. Section 3 presents the calibration assumptions and the simulation results. Section 4 concludes the paper.

2. Strategic Advantages and de Facto Standardization in the U.S. Home VCR Market

[6] The strategic advantage is an equilibrium outcome in pricing and R&D games, which in principle can be calculated from the primitives of the games. Refer to section 3 for the related computational issues.

We begin with a brief review of the structural demand function in Park (forthcoming(a)) in the market for newly introduced durable products with network externalities. In many examples of network externalities, products such as VCRs are durable goods. In the case of durable goods, the consumer may take into account not only the current utility but also the expected future utilities derived from the use of a product. This dynamic concern of the consumer is represented by the consumer's *valuation function*, which is composed of the average (of the present value of) network benefit and the average (of the present value of) stand-alone benefit of the product in current and future periods. To reflect consumers' idiosyncratic tastes for differentiated products, the stand-alone benefit is specified as in the nested logit model of McFadden (1973), Berry (1994) or Cardell (1997). Note that the network benefit in a period depends on the network size (the number of old and new users) of the product's format (VHS or Betamax in the VCR case). Hence the network benefit changes over time although the stand-alone benefit remains the same. The average network benefit of format g in period t, say N_{gt}, is called the *network effect* of the format in the period. That is,

$N_{gt} = \varphi \sum_{s \geq t} (1-\varphi)^{s-t} E_t[\kappa(B_{gs} + q_{gs})]$ where φ is the consumer's discount rate, $E_t[\cdot]$ is the rational expectation operator, $\kappa(\cdot)$ is a single-period network benefit function, and q_{gt} and B_{gt} are sales and installed base of format g in period t.

Then, we can obtain the market share function of product j, say S_{jt}, and the market share function of format g, say S_{gt}, in period t as follows.

$$S_{jt} = \frac{e^{(-\varphi\lambda p_{jt} + \delta_{jt} + N_{gt})/(1-\sigma)} D_{gt}^{-\sigma}}{1 + \sum_g D_{gt}^{(1-\sigma)}} \text{ and } S_{gt} = \frac{D_{gt}^{(1-\sigma)}}{1 + \sum_g D_{gt}^{(1-\sigma)}}, \quad (1)$$

where p_{jt} is the price of product j in period t, λ is the marginal utility of price in the nested logit model, δ_{jt} is the quality of product j, σ is the within-format correlation coefficient, and $D_{gt} = \sum_{j \in J_g} \exp[(-\varphi\lambda p_{jt} + \delta_{jt} + N_{gt})/(1-\sigma)]$ with J_g denoting the set of all the products of format g. The quality of product j, δ_{jt}, can be understood as a real function of product characteristics while the within-format correlation coefficient, σ, is greater than or equal to zero and less than one, and approaches one as the within-format correlation of utility levels goes to one. The demand function for product j in period t, say q_{jt}, is: $q_{jt} = M_t \cdot S_{jt}$, where M_t is the market size (the number of potential buyers).

Estimating the market share function in (1) and the corresponding pricing equation, Park (forthcoming(a)) quantitatively analyzes the extent to which network externalities contributed to the de facto standardization of the VHS format in the U.S. home VCR market during the years 1981 - 1988. The competition between the VHS format and the Betamax format is a well-known example of network externalities. During the years 1981 - 1988, neither VHS nor Betamax was significantly superior in performance, features or prices. Nonetheless, tipping toward and de facto standardization of the VHS format occurred. The estimation results in Park (forthcoming(a)) indicate that the network advantage of VHS explains at least 70.3 percent to 86.8 percent of the logarithm of relative sales of VHS to Betamax in each year. In other words, the network advantage of VHS was the key reason that VHS outsold during the years 1981 – 1988. Moreover, Park (forthcoming(a)) finds that an increase in the network advantage of VHS was an engine of tipping toward the VHS format, and in the early 1980's, the network advantage of VHS was mainly due to its expected dominance in the future. Noticing that the only difference between these two formats in the early 1980's was in installed bases accumulated prior to the network externalities in action (via the consumer's use of prerecorded videocassettes such as movie titles), Park (forthcoming(a)) infers that the small difference in the (initial) installed bases amplified the difference in sales between VHS and Betamax via network externalities and then was reinforced to be bigger. This amplification-reinforcement process in the presence of network externalities might be reinforced by the expected future dominance of VHS, and this expectation itself became the main reason for the network advantage of VHS in early 1980's. Hence we infer that the initial installed base advantage satisfied the critical advantage in the U.S. home VCR market.

The tipping and de facto standardization process in the U.S. home VCR market, however, was affected by the strategic maneuvering of sponsoring firms. For instance, there was a surge (an increase of the market share) of Betamax in 1983 in the process of the de facto standardization toward VHS. In the paper, based on the estimates of Park (forthcoming(a)), we will further analyze the strategic maneuvering of Betamax in the de facto standardization process. We begin by decomposing the log (or logarithm of) relative sales of the VHS format to Betamax format, say $\ln(q_{vt} / q_{bt})$, from the format market share function in (1) as follows. Henceforth, it is understood that all the variables are indexed by period t.

$$\ln(q_v/q_b) = [N_v - N_b] + [\delta_v - \delta_b] - \varphi\lambda[\overline{p}_v - \overline{p}_b] + (1-\sigma)\ln[\#(J_v)/\#(J_b)], \quad (2)$$

where δ_v (δ_b) is the average quality of VHS (Betamax) VCRs, $\overline{p}_v$ ($\overline{p}_b$) is the quality-adjusted average price of the VHS (Betamax) format, and $\#(J_v)$ ($\#(J_b)$) is the number (or the lineup) of VHS (Betamax) producers. Refer to the appendix for the derivation of (2). On the right-hand side of equation (2), the first term is called the network advantage of VHS, the second term the average quality advantage of VHS, the third term the average price advantage (*APA*) of VHS, and the last term the lineup advantage of VHS. The sum of the average quality advantage and *APA* (i.e., $[\delta_v - \delta_b] - \varphi\lambda[\overline{p}_v - \overline{p}_b]$) is called the average price/quality advantage (*APQA*), which measures the *strategic advantage* of VHS. The sum of *APQA* and the lineup advantage of VHS is called price/quality advantage (*PQA*) in the paper.

Figure 1 illustrates VHS's *PQA*, *APA* and *APQA* in each year for 1981 – 1988 except in 1985.[7] Since the distance between *APQA* and *APA* indicates the average quality advantage, we can infer that there was almost no difference in average quality between Betamax and VHS during these years except 1987 although Betamax maintained slight advantages until 1986.[8] However, VHS had a visible price advantage on average except in 1983, 1986, 1987 and 1988.[9] Overall the *APQA* of VHS had negative values in these four years, which implies that Betamax had strategic advantages in those years. Figure 1 implies that the surge of Betamax in 1983 was mainly due to the *APA* of Betamax. However, a more aggressive strategic maneuvering of Betamax in 1987 (primarily due to its average quality advantage) did not make any apparent interruption in the de facto standardization toward VHS.[10]

Although the strategic advantages of Betamax in 1983 and 1987 were relatively substantial (compared with those in 1986 and 1988) and resulted in the decreases in *PQA* of VHS from the previous levels, VHS's advantage in the lineup of producers dominated Betamax's *APQA* even in 1983 and 1987. Note that the difference between *PQA* and *APQA* of VHS represents the lineup advantage of VHS in figure 1. The lineup advantage of VHS was generated by the licensing agreements between the sponsors and the licensees which allow entry into the VHS lineup and the exit from the Betamax lineup. However, the reason that the more producers (or licensees) have positive effects on the format sales is consumers' preferences for the variety of the products which are reflected in the nested logit specification of the utility function. Different producers of the same format VCRs may still be differentiated by consumers' idiosyncratic tastes for the reliability and the brand images of the producers. Indeed, the within-

[7] Relevant data are not available in 1985.

[8] This conclusion is consistent with the perception discussed in Park (forthcoming(a)) and the published articles such as in *Consumers Reports* and others during 1980's.

[9] Note that during the years in question, many new VHS producers entered the U.S. market and they usually had focused on low-end models with relatively inexpensive prices.

[10] Considering that the installed base advantage of VHS became much bigger in 1987, these observations suggest the significance of the *applications barrier to entry* in the presence of (indirect) network externalities. We will revisit and detail this issue in section 3.

format correlation coefficient, σ, is estimated to be 0.805 in the U.S. home VCR case, which indicates that the VCRs of the same format are much closer substitutes to each other but still are perceived as differentiated products. Hence, the sponsor will have an incentive to license for product differentiation. On the other hand, more licensees might join the lineup of the VHS in the tipping and de facto standardization process which was mainly caused by its huge network advantages. Therefore, the lineup advantage of VHS reflects *indirect* contribution of the network advantage of VHS via increased product varieties.

3. Counterfactual Simulations

We now proceed to conduct several simulations to study the impacts of strategic maneuvering in price/quality advantages on the de facto standardization in the presence of network externalities. The counterfactual simulations of the paper are based on the decomposition of the format market share function in (2). Since we are mainly interested in the effects of hypothetical strategic advantages in price and product quality on the de facto standardization process, the strategic advantage (*APQA*) is considered a control variable in our simulations. Indeed, the strategic advantage is an equilibrium outcome in pricing and R&D games. In principle, we can adapt the computational algorithms in Pakes and McGuire (1994, 2001) to our simulations to solve the equilibrium. However, it will induce tremendous computational burden to explicitly solve the whole structural system of these games along with the specifications of the primitives of the games (leading to predatory behavior (with long purse) or successful R&D outcomes required to generate a critical advantage). For related computational issues, refer to Benkard (2000), Huang and Park (in process), and Park (2003). The following counterfactual simulations will indicate that there is no irreversible critical mass and the sponsor of a technology can reverse the tipping process if it has a critical advantage which depends on the difference in the installed bases and other factors of consumer expectations for future adoption rates.

3.1. Calibrations

We begin with the calibration of the lineup advantage. As discussed in section 2, the lineup advantage of VHS was generated by the product differentiation of various licensees, and higher (expected) relative sales of VHS to Betamax might induce a greater lineup advantage of VHS. Moreover, if the products of a format are perceived more differentiated (i.e., σ has a smaller value), the lineup advantage might be greater. Hence we assume as follows.

> ASSUMPTION 1: The lineup advantage of VHS, $(1-\sigma)\ln[\#(J_v)/\#(J_b)]$, is equal to a decreasing non-negative function of σ, say $f(\sigma)$, times the log relative sales of VHS to Betamax, $\ln(q_v/q_b)$.

Assumption 1 together with equation (2) implies that log relative sales of VHS to Betamax are multiplied by 1/(1- $f(\sigma)$) due to the lineup advantage of VHS. Table 1 reports the regression result of the lineup advantage of VHS onto the space spanned by the log relative sales of VHS to Betamax for the years from 1981 to 1988 except 1985. It turns out that the multiplier, $f(\sigma)$, is estimated to be almost same with 1 - σ. In addition, the lineup advantages of VHS are very well fitted by the estimated value: during the years, the lineup advantages divided by the fitted values of these advantages lie between 0.997 and 1.001.

As presented in section 2, the network effect is the average network benefit (in the current and future periods) projected by current available information such as installed bases, prices, product qualities and sales. However, in equation (2), we need only to calculate the network advantage (instead of the network effect itself) of VHS. Hence we will utilize the estimates of the network

TABLE 1

Regression of the Lineup Advantage of VHS

Variable	Estimate	St. Error
$\ln(q_v/q_b)$	0.195	0.00007

advantage of VHS in Park (forthcoming(a)) to calibrate the functional form of the network advantage of VHS which is assumed as follows.

ASSUMPTION 2: The network advantage, $N_v - N_b$, is a function of the installed base advantage, $B_v - B_b$, the average price quality advantage, $[\delta_v - \delta_b] - \varphi\lambda[\bar{p}_v - \bar{p}_b]$, and the log relative sales, $\ln(q_v/q_b)$.

To calibrate the functional form of the network advantage, we begin by regressing the network advantage onto the space spanned by the installed base advantage, the log relative sales, and the average price/quality advantage. However, it turns out that the average/price quality advantage contributes insignificantly to the prediction of the network advantage in our specific case. As shown in figure 1, there had been no substantial difference in the average price/quality advantage between VHS and Betamax for the years in question. Furthermore, our regression results indicate that the linear function of the installed base advantage and the log relative sales fits the network advantages very well: the network advantages divided by the fitted values of these advantages lie between 0.932 and 1.068. The linear regression result is reported in table 2.

TABLE 2
Regression of the Network Advantage of VHS

Variable	Estimate	St. Error
$\ln(q_v/q_b)$	0.745	0.039
$B_v - B_b$	0.012	0.006

There are several noteworthy issues in the calibration of the network advantages. First, although the linear function of the installed base advantage and the log relative sales fits the network advantages very well, the network advantages are underestimated only in 1983 and 1987 in which the average price/quality advantage of Betamax was substantial. The observation suggests that consumer expectations for network effects did not fully reflect the changes in log relative sales induced by a one-shot strategic advantage. Hence, in the following simulations, we may have downward biases in path of the log relative sales of VHS to Betamax induced by a one-shot strategic advantage of Betamax. Second, on the other hand, if the strategic advantage of Betamax is expected to sustain, the network advantage via the changes in log relative sales may not fully reflect consumer expectations for future network effects. In other wards, it is likely that an increased strategic advantage has more impacts on the de facto standardization process if the sustained average price/quality advantage affects the network advantages (or consumer expectations for the difference in network effects) directly as well. Lastly, if these exists any public policy or business strategy which can credibly affect consumer expectations for future adoption rates, it will, like the average price/quality advantage, affect network advantages directly as well as indirectly via changes in log relative sales, and thus can play a role in the adoption of technologies.

Based on the estimation results in table 1 and table 2 and the data on installed bases, we can simulate from equation (2) the changes of the relative sales induced by a different level of strategic advantages. In the beginning year of our simulations, say *t*, we have the information on the installed base advantage from our data. However, since we can calculate only the relative sales in year *t*, we need to have the total VCR sales in year *t* in order to calculate changes of the installed base advantages in year *t*+1 under different hypothetical situations. Since we do not explicitly solve the equilibrium of the entire structural model, we cannot predict the total VCR sales under different hypothetical situations. Hence, we assume the following in our simulations.

ASSUMPTION 3: The total sales remain the same as those in the actual data.

3.2. Results

Under the calibration assumptions, we now calculate from equation (2) the path of $\ln(q_b/q_v)$ in our counter-factual experiments, which will show that there is no irreversible critical mass and the sponsor of Betamax with the critical advantage could reverse the tipping process. As indicated in figure 2, VHS seems to have achieved the critical mass around 1982 and 1983. The one-shot strategic maneuvering of Betamax in 1983, as discussed in section 2, created only a temporary interruption in the tipping process toward VHS. In 1984, the yearly increase in the relative sales of VHS to Betamax had recovered, and the tipping process was back on track. The following simulations, however, will show that the sponsor of Betamax could reverse the tipping and de facto standardization process from 1983 if it had the strategic advantage in 1983 at the level of its 1987's or if it had sustained its strategic advantages with direct effects on consumer expectations for the network advantages. Hence, the seemingly critical mass of VHS in 1983 did not actually lead to the further rate of adoption to be self-sustaining.

Figures 3 - 5 illustrate the calculated paths of $\ln(q_v/q_b)$, $N_v - N_b$, and $B_v - B_b$ in our experiments. When the de facto standardization of VHS was fulfilled in 1988, the value of $\ln(q_v/q_b)$ was 3.749. Hence we assume that the de facto standardization of VHS is achieved if $\ln(q_v/q_b)$ gets bigger than 3.749 while the de facto standardization of Betamax is done if $\ln(q_v/q_b)$ gets smaller than -3.749.[11]

Figure 3 shows that the strategic advantage of Betamax in 1983, even if it had been lasting, was not sufficient to reverse the tipping process, and the de facto standardization of VHS might have been accomplished in 1989. However, the simulation in figure 4 shows that the sponsor of Betamax could reverse the tipping process toward VHS if it had the same amount of strategic advantages in 1983 as it did in 1987. In this case, the sales of Betamax would surpass those of VHS immediately from 1983. The log relative sales of VHS to Betamax, however, would rise in 1984 and then decrease from 1985 along with the rapid reversed tipping process toward Betamax. The strategic advantage was sufficient to reverse the installed base advantage from 1984, and the installed base advantage of Betamax became the main force of the de facto standardization toward Betamax from 1984 via the amplification-reinforcement process. The de facto standardization of Betamax would occur in 1989 under this scenario. Indeed, our simulations indicate that 42 percent of the 1987's strategic advantage of Betamax is the minimal advantage (i.e., critical advantage) to reverse the de facto standardization process. As discussed in section 3.1, our simulations may have downward biases in path of the log relative sales of VHS to Betamax induced by a one-shot strategic advantage of Betamax. However, these simulation results indicate the existence of the critical advantage although it might be underestimated in the current calibration.

There are a couple of noteworthy issues before we proceed. First, it is questionable whether Betamax was ever able to have strategic advantages as the level of 1987's. In 1987, VHS

[11] In principle, we need to calculate the value functions of the sponsors with further information on the sell-off values, which are very difficult to estimate or obtain.

already had huge installed based advantage and network advantage, and the tipping process was in its final stage. The strategic maneuvering of Betamax in 1987 might not be due to Betamax's technological advantages (e.g., providing high-edge models at a lower production cost). As discussed, the equilibrium price and product quaity will depend on strategic interactions as well. The big strategic advantage of Betamax in 1987 might be possible because the VHS producers did not aggressively respond to Betamax's deep price cut in the final stage of the de facto standardization. On the other hand, the Betamax producers might have had incentives to sell as many Betamax VCRs as possible prior to the de facto standardization. Recall that neither of the two formats could surpass the other during the years in question. Without any significant cost/quality advantages or long purse, an aggressive strategic maneuvering of Betamax in the earlier stage of the tipping process must have been matched by the strategic response of VHS. Second, the simulation result in figure 4 as well as the fact that the strategic advantage of Betamax had no significant impacts on the tipping process suggests the significance of the *applications barrier to entry* in the presence of (indirect) network externalities. In the presence of indirect network externalities, the network effect represents the consumer's average benefit from available software products (such as movie titles in the VCR case). Hence, we can infer that if an incumbent has a big advantage in network effects due to a great variety of available software products (as a function of installed base advantages), the potential rival even with a significant cost or quality advantage may not enter the market since the incumbent's network advantage dominates the potential entrant's advantage in cost or quality.[12]

As discussed in section 3.1, if the strategic advantage of Betamax is expected to sustain, the network advantage calibrated in table 2 may not fully reflect consumer expectations for the changes in network effects. Suppose now that the sustained average price/quality advantage

[12] Refer to Park (forthcoming(b)) for the interactions between hardware and software products. The related empirical studies include Gandal, Kende, and Rob (2000) which directly used the number of movie titles available to the CD players to examine the interdependence between consumers' CD player adoptions and the CD supplies.

affects the network advantages (or consumer expectations for the difference in network effects) directly as well. Figure 5 indicates that if the strategic advantage in price and quality contributes directly to the network advantage with the coefficient of 1.2, the tipping process would be reversed. The installed base advantage of VHS would rise in 1984 but begin to slide from 1985. From 1986, the Betamax sales would surpass those of VHS due to the advantage in price and quality along with reduced difference in installed bases. From 1987, Betamax would have the network advantage due to the higher relative sales and the sustained advantage in price and quality. From 1989, Betamax would begin to have the installed base advantage due to the cumulative sales difference since 1986. Finally, Betamax would become the de facto standard in 1992. Hence, an increased strategic advantage may have more impacts on the de facto standardization process if the sustained average price/quality advantage affects the network advantages directly as well.

4. Conclusion

The de facto standardization of the VHS format in the U.S. home VCR market is a well-known example of de facto standardization in the presence of network externalities. The estimation results in Park (forthcoming(a)) suggest that the small difference in the (initial) installed bases prior to network externalities in action lead ultimately to the de facto standardization of VHS via the amplification-reinforcement process. Apparently, this interpretation is consistent with the idea of critical mass. However, in the paper, we showed that the sponsor of Betamax engaged in the strategic maneuvering in this tipping and de facto standardization process, which was short of reversing the process. Furthermore, the counterfactual simulations indicated that there is no irreversible critical mass and the sponsor of a technology could have reversed the tipping process if it had the critical advantage. The critical advantage is not an absolute amount of strategic advantages in price and product quality but determined by the difference in installed bases and other factors which affect consumer expectations for future adoption rates. Hence, any public policy or business strategy which can credibly affect consumer expectations for future adoption rates will play a role in the adoption of technologies in the presence of network externalities.

Appendix

Let *v* denote VHS and *b* denote Betamax. From the market share function of formats in equation (1), the logarithm of the relative sales (log relative sales, hereafter) of the two formats can be decomposed into the sum of two differences as follows.

$$\ln(q_v / q_b) = [N_v - N_b] + (1-\sigma)[\ln(\sum_{j\in J_v} e^{\delta_j/(1-\sigma)}) - \ln(\sum_{j\in J_b} e^{\delta_j/(1-\sigma)}]. \quad \text{(A.1)}$$

Let $\overline{p}_j$ be the quality-adjusted price of product *j* in the VHS format defined as: $\overline{p}_j$ = $p_j - (\delta_j - \delta_v)/\varphi\lambda$. The quality-adjusted price of product *j* in the Betamax format can be defined similarly. Then the second term of the right-hand side in equation (A.1), if it is positive, represents the price/quality advantage (*PQA*) of VHS, which can be further decomposed as follows.

$$PQAV = [\delta_v - \delta_b] + (1-\sigma)[\sum_{j\in J_V} \exp(\frac{-\varphi\lambda\overline{p}_j}{1-\sigma}) - \sum_{j\in J_B} \exp(\frac{-\varphi\lambda\overline{p}_j}{1-\sigma})]. \quad \text{(A.2)}$$

We now define the quality-adjusted average price of the VHS format, say $\overline{p}_v$, as: $\overline{p}_v = -[(1-\sigma)/\varphi\lambda]\ln[\sum_{j\in J_v} \exp(\frac{-\varphi\lambda}{1-\sigma}\overline{p}_j)/\#(J_v)]$. The quality-adjusted average price of the

Betamax format, say $\overline{p}_b$, can be defined similarly. Then the second term of the right-hand side of equation (A.2) can be further decomposed as follows:

$$(1-\sigma)[\sum_{j\in J_V}\exp(\frac{-\varphi\lambda\overline{p}_j}{1-\sigma})-\sum_{j\in J_B}\exp(\frac{-\varphi\lambda\overline{p}_j}{1-\sigma})] =$$

$$-\varphi\lambda[\overline{p}_v-\overline{p}_b]+(1-\sigma)\ln[\#(J_v)/\#(J_b)]. \qquad \text{(A.3)}$$

Combining (A.1) to (A.3) together, we can obtain equation (2) of section 2.

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Figure 1
Decomposition of Price/Quality Advantage of VHS

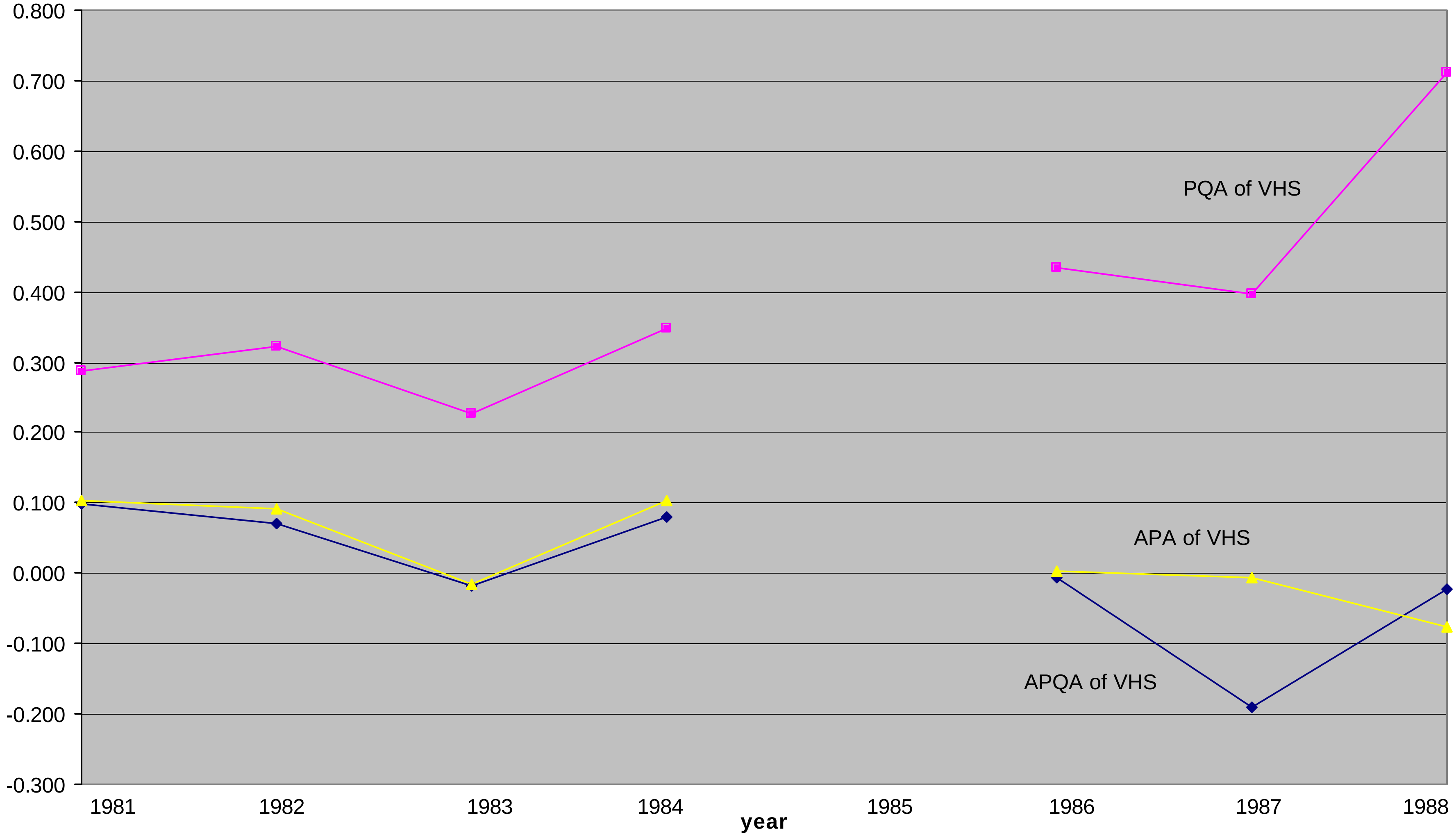

Figure 2
Sales of VHS and Betamax

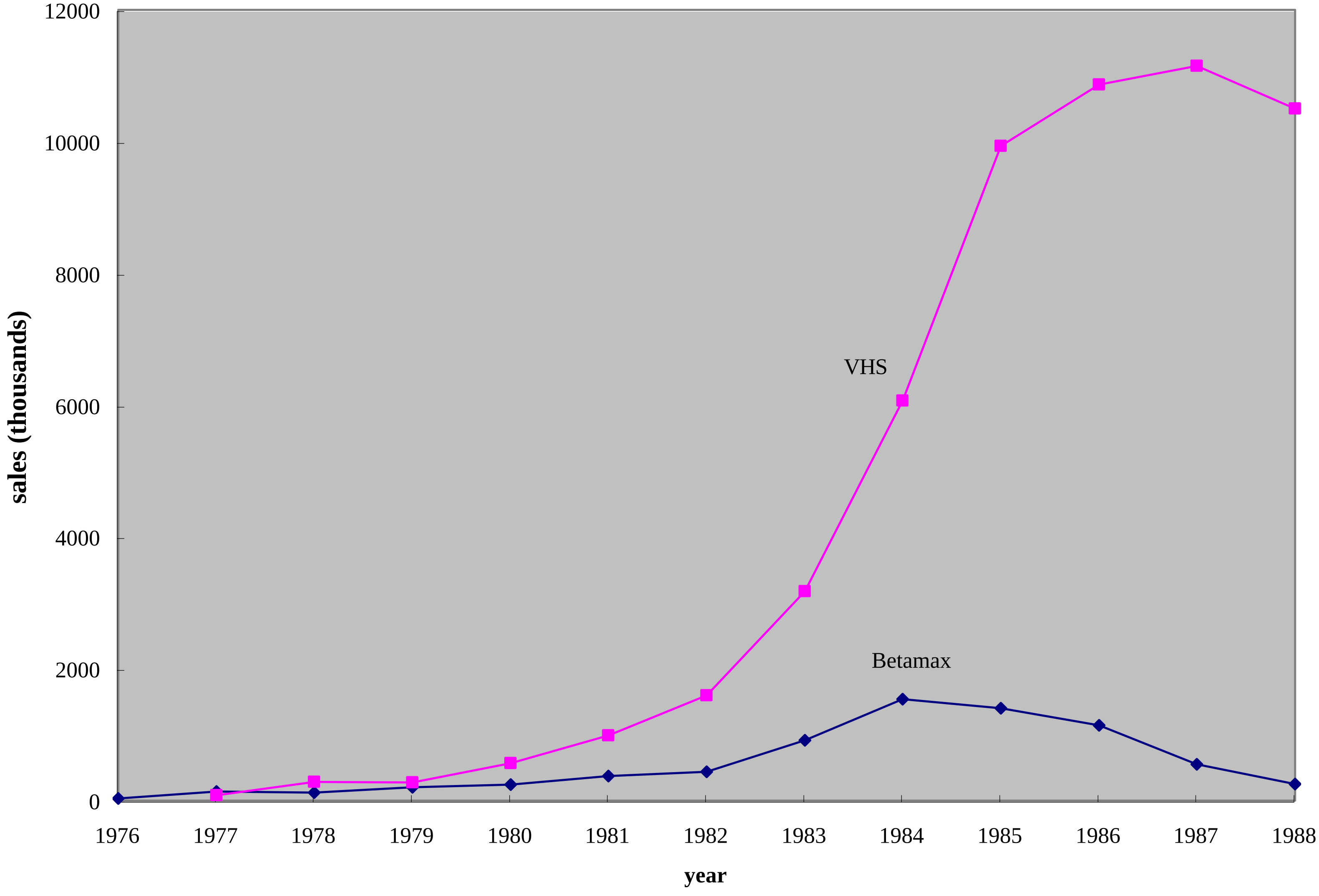

Figure 3
Sustained 1983's APQA of Betamax from 1983

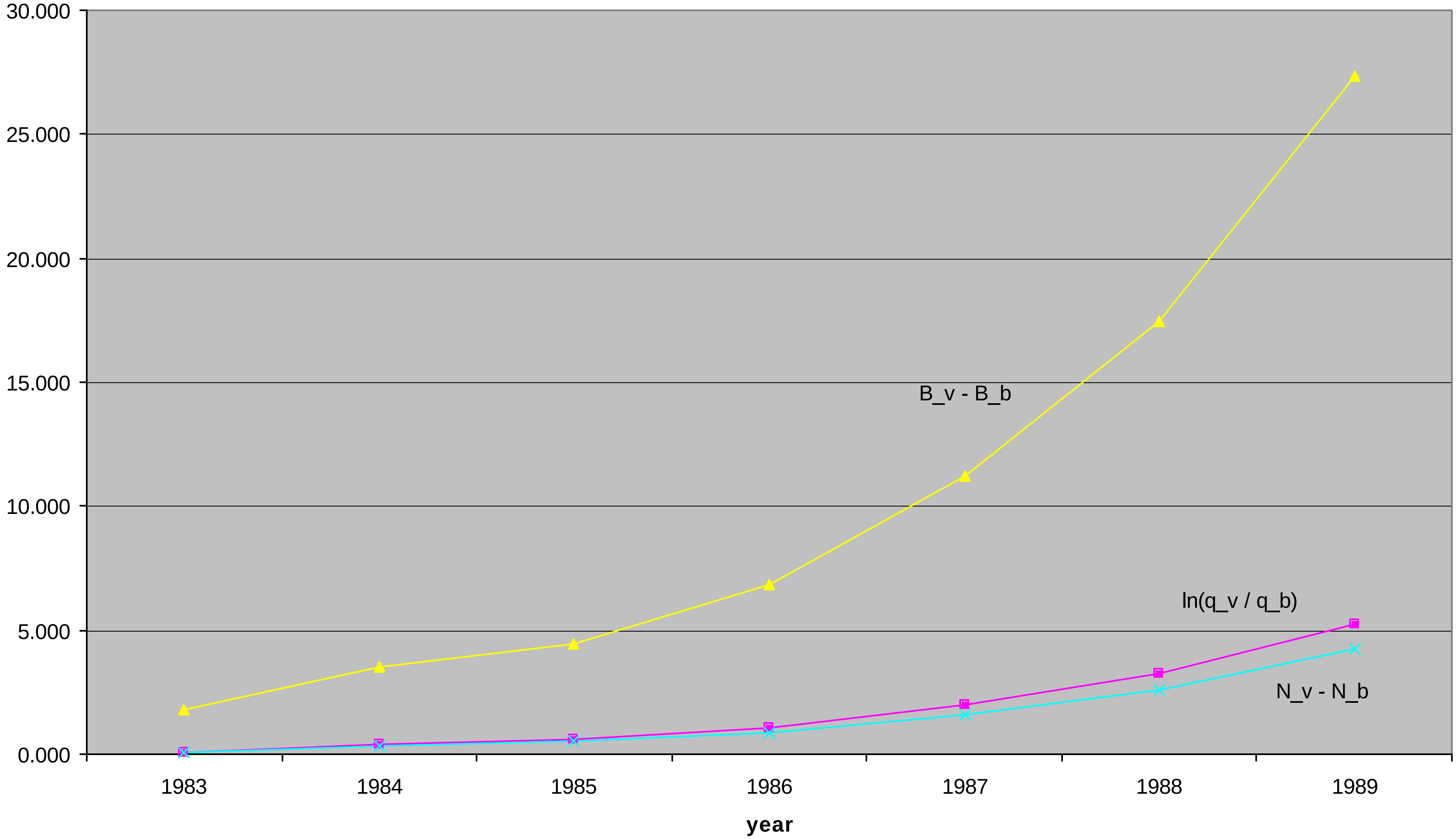

Figure 4
1987's APQA of Betamax in 1983

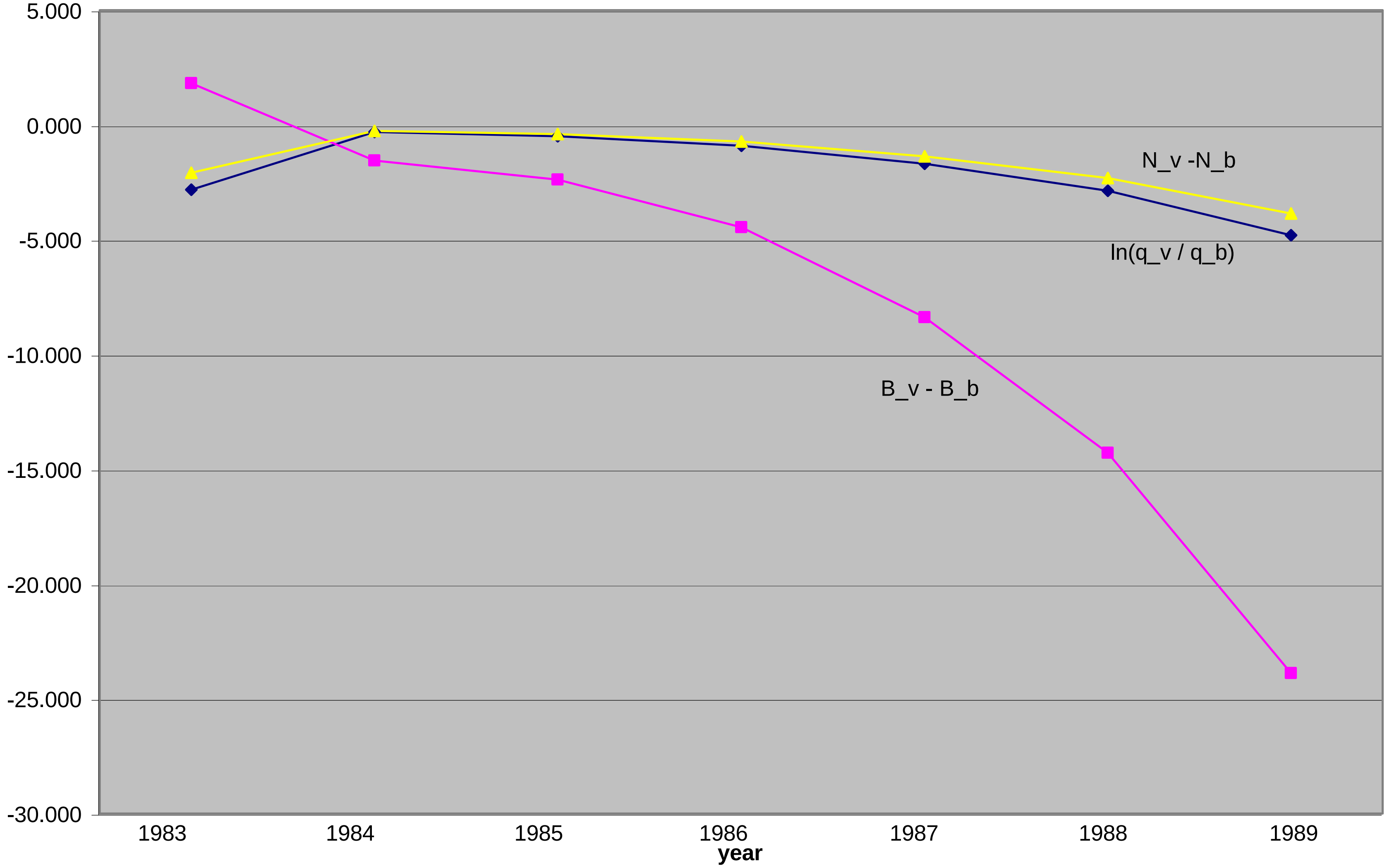

Figure 5
Sustained 1983's APQA of Betamax with Direct Effects on Consumer Expectations