EXPLORATION AND EXPLOITATION IN THE PRESENCE OF NETWORK EXTERNALITIES

Jongseok Lee[1], Jeho Lee[2], and Habin Lee[3]

Graduate School of Management[1, 2]
Korea Advanced Institute of Science and Technology, Seoul, Korea
Department of Electronic Commerce[3]
Paichai University, Taejon, Korea

ABSTRACT

This paper investigates the trade-off between exploitation of a dominant technology and exploration of a new technology in markets with network externalities. In our model, the new technology offers the higher potential for technological performance enhancement than the dominant one, but suffers from backward compatibility. Should firms place future bets on the dominant technology or the new one? Our simulation experiments show that the exploitation strategy is more conducive to firm survival and growth when a substantial part of customers are light users, who are sensitive to compatibility. However, if the consumer population consists of a large portion of power users, who are more sensitive to technological performance than compatibility, or if there remains enough demand that is waiting for adoption of a technology, the exploration strategy is shown to be more effective. Furthermore, our model suggests that power users can play a key role in overcoming the lock-in problem.

KEYWORDS

Exploration; Exploitation; Network Externalities; Lock-in; Innovation

1. Introduction

The emergence of a new technology with unknown commercial possibilities, yet promising superior performance to an existing technology, can cause a strategic dilemma for incumbents. This knotty decision problem is generally known as the trade-off between exploration of new possibilities and exploitation of existing opportunities, which has been a pivotal theme in research on adaptive systems [1, 2, 3, 4]. Generally, it is unknown *ex ante* whether an inferior, dominant technology eventually drives out a new superior technology. Should, then, firms place future bets on new technological opportunities or exploit existing technological opportunities? The objective of this paper is to address this issue by modeling the situation of two competing technologies subject to network externalities.

2. Exploration and Exploitation in the Presence of Network Externalities

The literature seems to diverge into two contrasting views regarding whether exploration or exploitation is more crucial in terms of the firm's long-run survival and growth. The two views are the learning myopia and the lock-in arguments. In the learning myopia argument, the potential downfall of firms in the absence of exploration has been emphasized in a number of studies [5, 6]. Although exploitation of the existing technology may be conducive to firm survival in the immediate future, too much exploitation to the exclusion of exploration will be detrimental to firm survival in the long run. Learning has the self-reinforcing nature in such a way that there are increasing gains with respect to experience in a technology. Firms with sufficient experience with one technology tend to be blinded to see opportunities from a new technology, which requires time and efforts to achieve a desired level. As March [3: 73] noted, however, "Since long-run intelligence depends on sustaining a reasonable level of exploration, these tendencies to increase exploitation and reduce exploration make adaptive processes potentially self-destructive."

On the other hand, another stream of research, what we call "the lock-in argument", has focused on excessive inertia associated with a dominant technology [7, 8, 9]. This literature, in contrast, has suggested the possibility that firms exploiting a dominant technology drive out firms exploring a new technology. When a market for a given product is subject to network externalities, the value of the product increases with the number of consumers using compatible products. This literature has emphasized benefits from compatibility: firms can add value to a product by achieving compatibility with the installed base. When these firms grow faster and dominate the market, there may not be room for firms exploring a new technology. Then, the market evolution will result in lock-in to a dominant technology.

From the survey of the literature, it becomes rather clear that neither exploration nor exploitation alone always leads to the long-term survival of the firm. A choice between the two strategies reflects a tension between performance and compatibility [10]: whereas firms with exploitation strategy may benefit from network externalities at the cost of compelling performance, firms with the exploration strategy may benefit from superior product qualities at the cost of backward compatibility. A relevant question is, under what circumstances does each of the two play a more important role in firm survival? This paper addresses this question by showing when the benefit from backward compatibility outweighs that from compelling performance or vice versa.

In addition, the lock-in argument brought about a controversy in the literature. Despite the popularity of the lock-in argument, empirical observations generally do not support this story [11, 12]. In this vein, Katz and Shapiro [13: 108] noted: " Although it seems plausible that the inertia associated with network effects has somehow deprived us of valuable new technologies, it is abundantly clear that many new, incompatible technologies are in fact successfully introduced." Then, how can new technologies become successful in the market? There seem to be two keys that can limit the lock-in tendency. They are technological innovation and consumer heterogeneity [13].

However, most models in the literature do not explicitly take the supply side into account by focusing only on the demand aspects. Competing technologies are exogenously given in the models. In the model that we will develop in the next section, we incorporate both supply-side [4, 14] and demand-side factors. With this integrated model, we sort out the murky issue.

3. The Model

In the model that follows, we analyze the dynamics of industry evolution where there are two competing technologies subject to network externalities. Initially, firms develop products based on one technology and individual consumers begin to adopt these products. Then, a new, competing technology emerges and offers higher potential for improving quality of products. However, this technology is incompatible with the installed base. In this situation, incumbent firms inevitably face the trade-off between compatibility and performance. Firms can keep exploiting the technology-in-use in order to ensure backward compatibility and thus benefit from network externalities. Alternatively, they can explore a new technology in order to sharply increase technological performance at the cost of compatibility. Here, firms' strategic choice falls into two categories: the exploitation strategy versus the exploration strategy. Under what circumstances does each of the two play a more important role in firm survival? Our model mainly consists of two parts: the demand-side and the supply-side dynamics.

Demand-side Dynamics: Product Adoption

Let us first turn to the demand-side dynamics. Consider a product characterized by network externalities and incessant improvement of product qualities over time. We assume that consumers are heterogeneous in adopting a product. In particular, consumer's utility consists of two parts: utility associated with product quality, and utility attached to network externalities. Based on these two factors, each consumer makes decision regarding the purchase or repurchase of either one or no unit in every period. Formally, this idea can be expressed as follows:

$$U_{it} = d_i + q_{jt}^k + a_i n_{t-1}^k$$

where U_{it} = consumer i's total utility at time t, d_i = consumer i's disposition to a product, q_{jt}^k = the quality of product that firm j produced based on technology k (k is either an old technology or a new technology) at time t, a_i = consumer i's sensitivity to network externalities, and n_{t-1}^k = the network size for products based on technology k at time t-1.

The above representation can be interpreted that consumers regard the product quality and the network size as substitutes: a high value in the network externality can offset a low value in the product quality, or vice versa.

Therefore, in the presence of network externalities, the demand-side adoption of a product arises because not only of its superior quality, but also of its network size. As a result, a technologically inferior product may be adopted by consumers thanks to benefit from its large network of users or installed base.

The consumer population consists of two types, power users and light users. Power users are often scientists or engineers, who attach much greater importance to product quality than light users. At the same time, power users are less sensitive to network externalities than light users. In addition, power users have on average higher preference for a product than light users (See Lee, Lee, and Lee [15] for further technical details). In our model, demand for products consists of new purchases and repurchases. New purchases of products are generated by neophytes who have not yet adopted any products. On the other hand, repurchases are generated by experienced customers who have already owned the products.

Each consumer purchases or repurchases the product that maximizes his or her surplus, which is the consumer's total utility less the price of a product. Each customer considers all products available in market, evaluates their surpluses, and makes purchase decision based on these comparisons. In particular, he or she chooses a product whose surplus is non-negative and largest. If none of the products satisfy the non-negativity condition, this customer does not buy any product at time t. This means that this customer's purchase or repurchase will be delayed until the product qualities and the network sizes sufficiently increase.

Supply-side Dynamics: Technological Advance

We turn now to the supply-side dynamics, which describe innovation, firm growth and exit processes over time. Formally, firm j's capital at time $t+1$, $\boldsymbol{K}_{jt+1}$ is

$$\boldsymbol{K}_{jt+1} = \boldsymbol{K}_{jt} + \boldsymbol{R}_{jt} - \boldsymbol{CP}_{jt} - \boldsymbol{CR}_{jt}$$

where $\boldsymbol{K}_{jt}$ = firm j's capital at time t, $\boldsymbol{R}_{jt}$ = firm j's revenue at time t, $\boldsymbol{CP}_{jt}$ = firm j's plant-building cost at time t, $\boldsymbol{CR}_{jt}$ = firm j's R&D cost at time t. Here, firm growth is shaped by returns from sales of products less costs. Firm j will have positive sales at time t only if the quality of its products satisfies a consumer's need. If a firm constantly fails to generate returns, its capital declines and reaches an absorbing state of insolvency. This happens when its capital is below the minimum R&D cost. We assume that firm j invests $\boldsymbol{CP}_{jt}$ for an increase in a unit of its plants at time t only if it sold out its products at time t-1 [16].

In our model, the firm's long run survival depends on the choice of R&D investment, given the trade-off between compatibility and performance. Since the size of the firm's installed base further boosts its sales, the firm can choose to invest all of its R&D expenditure CR_{jt} in the existing technology. Alternatively, the firm can sharply improve the quality of its products by betting CR_{jt} on a new technology. Product quality with respect to technology k, q_{jt}^{k}, is a random variable, which follows a beta distribution. It is assumed that a new technology offers the higher potential for technolgical performance enhancement than an old technology, and that the firm's draw of product quality is a function of its cumulative R&D investments (See Lee, Lee, and Lee [15] for further technical details).

4. Simulation Results

The simulations reported here numerically map out the effects of network externalities and Schumpeterian competition on the industry dynamics. We start with the simulation of the standard parameter setting, where there are 500 firms for exploration and 500 firms for exploitation (See Lee, Lee, and Lee [15] for details). To examine the effect of exploration alone, let us turn to the case in the absence of network externalities. As shown in the second and third columns of Table 1, the exploration group outperforms the exploitation group. The number of survivors in the exploration group increases from 9 to 18, whereas that of survivors in the exploitation group does not change. Also, the aggregate capital for the exploration group is more than four times that for the exploitation group at the end of simulation run.

On the other hand, when demand is sensitive to network externalities, the results show that exploiting the established technology results in better survival and growth than otherwise. This is captured in the fourth and fifth columns in Table 1. The number of survivors in the exploitation group increases from 19 to 23, whereas that of survivors in the exploration group decreases from 20 to 13. Also, the aggregate capital for the exploitation group is about three times that for the exploration group. This result suggests firms can survive and prosper by indulging in the exploitation of the established technology in the presence of network externalities.

Now, we turn to the central questions raised in the second section: Under what circumstances would the exploration group better perform than the exploitation group in the long run? What makes the market system lock into an obsolete technology? To answer these questions, we experiment with the standard model, which is characterized by the presence of network externalities and exploration effects. Here we vary two key factors: (1) the proportion of power users to light users in the consumer population, and (2) the timing of the emergence of a new technology.

Figure 1 shows how variation in the proportion of power users affects the aggregate capital for survivors at the end of simulation runs. Whenever the proportion of power users is not less than 20 percent, the aggregate capital of the exploration group is larger than that of the exploitation group. These results indicate that the exploitation strategy is more effective in terms of firm survival and growth when a substantial part of consumers are not power users.

However, when power users represent larger proportion of consumer population, the exploration strategy is more effective.

The above results suggest that the power users play a critical role in sustaining incompatible technologies by limiting tipping toward a single dominant technology. Moreover, the power users can provide the exploration group with a foothold to fight against an established technology. As the number of power users gets larger, more and more firms find exploration worthwhile.

Figure 2 shows how variation in the timing of the emergence of a new technology affects the aggregate capital for survivors at the end of simulation runs. As long as the new technology emerges before period 40, the aggregate capital of the exploration group is larger than that of the exploitation group. However, the result goes the other way around wherever the new technology is introduced after period 50. This happens because the later the new technology emerges, the larger the installed base associated with the established technology becomes.

5. Discussion and Conclusion

We examined whether exploitation of an established technology, or exploration of a new technology, is more conducive to firm survival in the presence of network externalities. Our study resolved a seeming controversy regarding the trade-off between exploration and exploitation by sorting out conditions under which each alternative is more conducive to firm survival. Our simulation experiments show that the exploitation strategy is more likely to increase the chance of firm survival and growth when a substantial part of consumers are not power users. But in the presence of a large number of power users, the exploration strategy is shown to be more effective. When a new technology emerges in the early stage of the industry evolution so that there remains enough demand waiting for adoption of a technology, the exploration strategy is shown to be more effective, too.

In addition, our model offers an answer to a puzzling question in the literature. Despite the popularity of Arthur's [9] lock-in argument, Leboiwtz and Margolis [11, 12] argued that history of technology competition has rarely shown the possibility of lock-in to an inferior technology. Furthermore, Leboiwtz and Margolis [12] alluded that the lock-in problem can be somehow solved in the market characterized by Schumpeterian competition. Thus, the supply-side dynamics matter in the discussion of the lock-in problem. Yet, sparse attention has been paid to this in the literature, where much of discussion comprises the demand-side stories under the name of network externalities. In this vein, Katz and Shapiro [13: 106] noted: "Rather little theoretical work has been done on R&D and technology choice in the presence of network effects and uncertain technological progress." In our model we incorporate both supply-side and demand-side factors in an attempt to solve this puzzle.

Our model suggests a potential mechanism for overcoming the lock-in problem. When a market exhibits lock-in to an obsolete technology, the survival of a new technology depends on power users. When many power users are cultivated by firms' technological efforts (e.g., development of killer applications associated with a new technology), the market is less likely to lock into the obsolete technology. Indeed, in the workstation market, where power users characterize much of demand, firms successfully switched to the RISC architecture. This is in contrast to the PC market where a large portion of demand comes from light users, who are sensitive to compatibility.

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Table 1. Effects of Exploration and Network Externalities: Result of 100 Simulation Runs

	Absence of Network Externalities		Presence of Network Externalities	
	No Exploration	With Exploration	No Exploration	With Exploration
Total Sales	50,501	66,095	68,964	70,703
Number of Survivors	18	27	39	36
Exploitation Group	9	9	19	23
Exploration Group	9	18	20	13
Aggregate Capital*	147,159	154,323	150,057	166,070
Exploitation Group	72,756	30,897	73,397	123,781
Exploration Group	74,403	123,426	76,660	42,289

* Aggregate capital = the number of survivors ×the average capital

Figure 1. Effect of the proportion of power users on the aggregate capital of each group: A typical simulation run

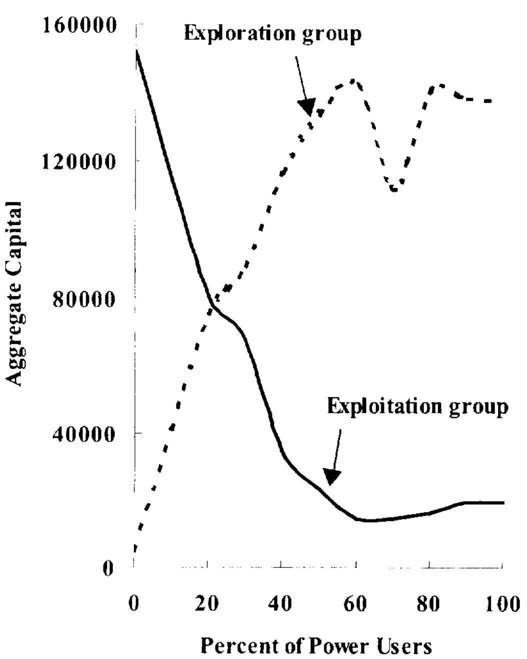

Figure 2. Effect of the timing of the emergence of a new technology on the aggregate capital of each group: A typical simulation run