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## **Evolutionary Model of Changes in Industrial Leadership and Catch-up by Latecomers: Role of the “Incumbent Trap”**

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### **Abstract**

Enrollment: 2011 to June 2016. 1) State-of-the-art: Lee and Malerba (2015) develop an appreciative theory on how industrial leadership changes from incumbents to latecomers and argue that the change is associated with “incumbent trap,” a phenomenon in which incumbents stick to old technology instead of adopting a new one. Case studies find this phenomenon in the history of leadership changes in various industries. 2) Research Gap: However, the literature insufficiently identifies the conditions under which incumbent traps, and thus industrial leadership changes, occur. This study identifies these conditions. 3) Theoretical arguments: When a new technology (NT) is introduced, changes in industrial leadership from incumbent leaders to latecomers are more likely to occur when the initial performance level of the NT is close to but lower than the highest performance level of the established one, which is normally achieved by the firm with the largest market share. 4) Methods: This study develops a Nelson–Winter-like model in which firms employ a process technology to produce a homogeneous product, and their market shares are determined by cost (and thus productivity) competition. Firm productivity of a specific technology is the sum of basic productivity (BP) that is exogenously given at the time of the arrival of the technology and additional productivity through learning-by-doing of the firm and the industry. 5) Results: If the BP of an NT is lower than a certain level (point A) that is close to but lower than the highest productivity of the established technology (point B), a leadership change occurs with a low frequency. If the BP of an NT is between points A and B, the leadership change frequency is high. Beyond point B, the frequency is moderate. Interestingly, an inverted-U relationship between the BP of an NT and leadership change is found between points A and B. The reason is that, beyond a certain point in this range, a higher BP of NTs prompts incumbent leaders to adopt NTs not long after latecomers do. Thus, the initial productivities of the leaders of the NT lag only a little behind the productivities of the latecomers who adopted it first. The small productivity lag is overcome by the larger capital of the leaders before long. As a result, the leaders increasingly succeed in leadership defense on the right-hand side of the inverted-U curve. \*\* Reference: Lee, K., Malerba, F., 2015. Toward a theory of catch up cycles and changes in industrial leadership, *Research Policy* (forthcoming in a special issue). An earlier version was presented at Globelics 2013, Ankara, Turkey.

# Evolutionary Model of Changes in Industrial Leadership and Catch-up by Latecomers: The Role of the “Incumbent Trap”

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## Abstract

Lee and Malerba (2015) develop an appreciative theory on how industrial leadership changes from incumbents to latecomers and argue that the change is associated with “incumbent trap,” a phenomenon in which incumbents stick to old technology instead of adopting a new one. Case studies find this phenomenon in the history of leadership changes in various industries. However, the literature insufficiently identifies the conditions under which incumbent traps, and thus industrial leadership changes, occur. This study identifies these conditions. When a new technology (NT) is introduced, changes in industrial leadership from incumbent leaders to latecomers are more likely to occur when the initial performance level of the NT is close to but lower than the highest performance level of the established one, which is normally achieved by the firm with the largest market share. This study develops a Nelson–Winter-like model in which firms employ a process technology to produce a homogeneous product, and their market shares are determined by cost (and thus productivity) competition. Firm productivity of a specific technology is the sum of basic productivity (BP) that is exogenously given at the time of the arrival of the technology and additional productivity through learning-by-doing of the firm and the industry. If the BP of an NT is lower than a certain level (point A) that is close to but lower than the highest productivity of the established technology (point B), a leadership change occurs with a low frequency. If the BP of an NT is between points A and B, the leadership change frequency is high. Beyond point B, the frequency is moderate. Interestingly, an inverted-U relationship between the BP of an NT and leadership change is found between points A and B. The reason is that, beyond a certain point in this range, a higher BP of NTs prompts incumbent leaders to adopt NTs not long after latecomers do. Thus, the initial productivities of the leaders of the NT lag only a little behind the productivities of the latecomers who adopted it first. The small productivity lag is overcome by the larger capital of the leaders before long. As a result, the leaders increasingly succeed in leadership defense on the right-hand side of the inverted-U curve. The key contribution of this study is to reveal that the optimal range of the initial performance of the NT exists in which the incumbent trap and therefore leadership changes are more likely to occur.

**Keywords:** simulation [ABM], incumbent trap (in changes in industrial leadership and catch-up by latecomers)

## 1. Introduction

Lee and Malerba (2016) propose an appreciative theory to explain why successive changes in industrial leadership occur over time from an incumbent country or firm to a latecomer. The theory argues that these changes are associated with the “incumbent trap,” a phenomenon in which incumbent firms tend to cling to an old technology (OT), whereas latecomer firms adopt a new technology (NT), when such technology arises. Although the incumbent trap has an important role in the above theory, the conditions under which it occurs and the variations of its effects under such conditions are left unexplored. This insufficiency is partly compensated for by the companion paper Landini et al. (2015), which develops a formal simulation model to replicate different patterns of leadership changes and to explore their determinants. In their model, the incumbent trap serves as one of the four determinants. However, in their modeling of the phenomenon, one of the most fundamental technological conditions that are associated with it is missed: the level of the initial performance of the NT. The effects of the incumbent trap on leadership changes vary with this level because this level is a key factor in a firm’s decision to adopt the NT. The present study develops a formal model to explore how the effects of the incumbent trap on leadership change vary with the level of the initial performance of the NT.

By developing a Nelson–Winter-like simulation model, this study first reproduces a change in industrial leadership from an incumbent leader firm to a latecomer firm and then explores the relationship between the level of the initial performance of the NT and the occurrence of an incumbent trap, and consequently a change in industrial leadership. When an NT (i.e., a new production technology) is introduced in an industry, a firm has to decide whether to adopt it or not. One of the major issues in the adoption decision is whether or not the firm is able to achieve a better performance (e.g., higher productivity) by adopting the NT. I hypothesize that, when the initial performance of an NT is low, leadership changes are less likely to occur. When it is too high, leadership changes are moderately likely to occur. When it is high, leadership changes are more likely to occur because the incumbent trap occurs. Furthermore, the higher it is, the more likely the incumbent trap and therefore leadership changes occur.

The model I investigate is an industry in which several firms produce a single homogeneous product. In the model, technology means production technology, and the competition of firms is based on productivity. A firm improves its productivity of a specific technology through learning by doing. An NT exogenously arrives in the industry with a basic productivity (BP) level, which is taken as the initial productivity of a firm that adopts the NT at the very period when it is introduced in the industry. A firm decides whether to adopt an NT or not every period following its arrival based on a comparison of the expected productivity of the OT and that of the NT. No R&D is conducted by the firms themselves, which will be loosened at later versions. As an individual firm improves its

productivity of the technology it currently employs through learning by doing (individual learning by doing), a spillover effect occurs in the productivity improvement among the firms using the same technology (collective learning by doing). From the perspective of evolutionary economics, firms are modelled as rule- or routine-based adaptive agents who seek, instead of maximize, profits (Nelson and Winter 1982) when they decide the output levels and adoption of an NT. Leadership is measured by the market share.

By changing the value of the parameter of the level of the BP of the NT, different dynamics of leadership change are observed. I obtain the distribution of the frequency of leadership change through hundreds of iteration of each value of the parameter. The results are identical to the hypothesis except for one factor. When the level of the BP of the NT is low, leadership changes are less likely to occur. When it is too high, leadership changes are moderately likely to occur. When it is high, leadership changes are more likely to occur because incumbent trap occurs. However, in the range where I define the BP of the NT as “high,” an inverted-U relationship, instead of a hypothesized monotonically increasing relationship, is found between the BP of the NT and leadership change. The reason for this is, beyond a certain level of the BP of the NT, a higher BP of the NT prompts incumbent leaders to adopt the NT not long after latecomers do. In other words, the incumbents quickly escape the incumbent trap.

The contribution of this study is to reveal that the optimal range of the initial performance of the NT exists in which the incumbent trap and therefore leadership changes are more likely to occur and to confirm that the probability of a leadership change has an inverted U-shaped relationship with the level of the initial performance of the NT in that range.

## **2. A Hypothesis**

The concept of incumbent trap is introduced by Chandy and Tellis (2000). Lee and Malerba (2015b) use this concept to explain a change in industrial leadership from an incumbent leader to a latecomer. In their companion papers on industry case studies use this concept to explain the actual cases of leadership change (Camera: Kang and Song (2015); Steel: Lee and Ki (2015), etc.). Similar concepts includes innovator’s dilemma (Christensen 1997) and a window of opportunity (Perez and Soete 1988). (The comparison between incumbent trap and those will be detailed.)

When a new production technology is introduced in an industry, firms evaluate the said technology to determine whether to adopt it or not. One of the major issues is in this adoption decision, whether or not the firm is able to achieve a higher productivity by adopting the NT than by maintaining the OT. If yes, the firm adopts the former; otherwise, it does not. In other words, in its decision do adopt a technology, a firm compares the expected productivity of the NT with that of the OT it is currently

employing.

Incumbent firms normally achieve a higher performance with an existing technology than latecomers because the former have been using it much longer and therefore have accumulated much knowledge on it. By contrast, latecomer firms normally have less time with the OT and therefore have less accumulated knowledge on it than incumbents. Thus, in evaluating an NT, incumbents tend to decide not to adopt it because their knowledge on the OT tends to enable them to have higher performance when they maintain the latter than when they replace it with the former.

Before any further discussion to ground the formulation of a hypothesis, I first define the productivity of a production technology at the time of its arrival as its BP, which is a characteristic of the said technology and is disclosed to all the firms in the industry. The BP of a technology does not change over time. I additionally define the productivity that a firm achieves by learning (i.e., via its production experience and R&D) after adopting a specific technology as the firm's total productivity (TP). The TP of a specific technology can vary across firms. The BP of a technology is the same for all the firms in an industry. After the technology is adopted, different firms have different TPs according to their learning. BP is a main factor that comprises the expectation value of the TP of an NT when a firm evaluates the NT. The literature usually assumes that the NT is initially inferior to the OT (Malerba et al. 2007) and insufficiently identifies how the level of the BP of the NT influences the probability of changes in industrial leadership and catch-up by latecomers. I formulate a hypothesis on this issue.

First of all, even when no new technology is introduced in an industry, a change in industrial leadership can occur for many reasons. We refer to the probability of a change in leadership with no new technology introduced as the baseline probability of a leadership change.

If the BP of an NT is as low as any firm using an OT doesn't adopt the NT at the time of its arrival, the appearance of the NT does not affect the baseline of leadership change.

If the BP of an NT is above a certain level, some (but not all) of the firms in an industry recognize at the time of its arrival that the expected TP of the NT is higher than that of the OT they have been using and thus adopt the NT. We refer to this level as level A. If the BP of the NT is (the same as and) above another certain level beyond level A, all the firms in the industry evaluate at the time of the arrival of the NT that the expected TP of the NT is higher than that of the OT they have been using and thus adopt the NT. We refer to this level as level B. In fact, level B is the highest productivity of the old technology achieved by a firm in the industry, which is normally achieved by the firm with the largest market share.

Between levels A and B, some (but not all) of the firms in the industry adopt the NT at the time of the arrival of the NT; these firms are latecomers. The reason is that given that incumbents usually have a

higher TP of the OT than latecomers, if the BP of the NT is as high as to make some (but not all) of the firms in the industry adopt the NT at the time of its arrival, it is latecomers that adopt it. The reason is that the TPs of the OT of the latecomers are lower than the BP of the NT.

For a better understanding, I give an example. Suppose there are 4 firms (Firms 1, 2, 3, and 4) in an industry and their TPs and the timing of industry entry differs among them: the entry order from the earliest to the latest is Firm 1, 2, 3, and 4. With other things the same, the TP order tends to be identical to the entry order and I suppose that equality for this example. That is the TP order from the highest to the lowest is Firm 1, 2, 3, and 4. In this situation, suppose that a NT is introduced in the industry, and its BP is lower than the TPs of Firms 1 and 2 and is higher than those of Firms 3 and 4. By assuming that a firm's adoption rule is very simply to compare their TP of the OT and with the BP of the NT, we conclude that at the time when the NT is introduced in the industry, Firms 1 and 2 don't adopt the NT whereas Firms 3 and 4 adopt it. This is the phenomenon of the incumbent trap (Lee and Malerba 2015, Chandy and Tellis 2000). Incumbents that cling to an OT may have a good reason to do so. They may want to enjoy the higher productivity of the OT that they have achieved through their large investment on it. Note that the difference in decision on NT adoption occurs even with an assumption that all the firms have the same evaluation of the BP of the NT. The reason is that different firms have different TPs of the OT. Meanwhile, even without an individual firm's R&D related to the technology, different firms have different TPs of the OT. The reason is that different firms produce different amounts of a product using the OT and therefore the effects of learning by doing on the said technology vary across firms.

Suppose that the OT and NT have the same learning curve except for the starting value of the productivity (which is due to difference between the BPs of the OT and NT). The learning curve is assumed to have a form of diminishing returns. NT-adopting firms are at the starting point of the learning curve of the NT so that they improve their TP of the NT faster than OT-keeping firms do that of the OT because OT-keeping firms are at around at the latter part of the OT's learning curve. Incumbents adopt the NT a little later than latecomers if their expectations of the TP of the NT eventually become higher than that of the OT. However, their later adoption places them behind the latecomers in terms of the learning curve of the NT. In other words, latecomers have an advantage in terms of productivity over incumbents. Accordingly, a firm with the largest market share changes from an incumbent leader to a latecomer.

To sum up the case in which the BP of the NT is between levels A and B, which means the BP of the NT is as high as to make some of the firms in the industry adopt the NT but not as high as to make all the firms adopt the NT, the probability of a change in industrial leadership from an incumbent leader to a latecomer is substantially higher than the baseline probability of a leadership change.

More importantly, when the BP of the NT is between levels A and B, as the BP of the NT becomes

higher, more firms adopt it at the time of its arrival. The more firms that adopt the NT, the more quickly NT-adopting firms improve their TP of the NT because the more number of firms create the spillover effect in knowledge among the firms that have adopted the same technology. In addition, the higher the BP of the NT is, the smaller the initial gap is between the TPs of the firms with the OT and the firms with the NT. This means that the firms with the NT do not take long time to catch up with and surpass the firms with the OT in terms of TP. Given these two facts, I additionally hypothesize that when the BP of the NT is between levels A and B, a higher BP of the NT is more likely to result in a change in industrial leadership.

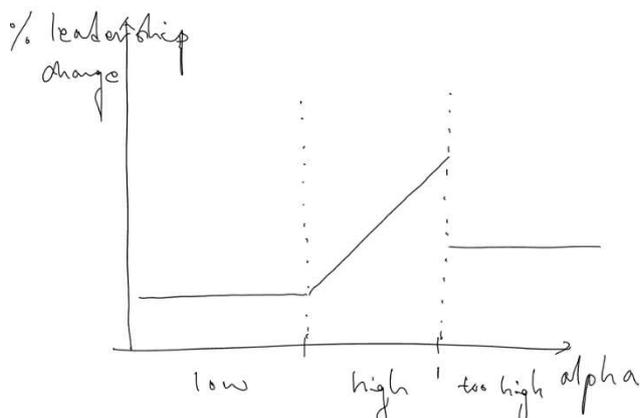
If the BP of the NT is the same as and higher than level B, the highest productivity of the old technology achieved by a firm in the industry, which is normally achieved by the firm with the largest market share, all the firms using the OT adopt the NT immediately at the time of its arrival. This means that all the firms start at the same point on the learning curve of the NT, and the advantage of the incumbents over the latecomers in terms of the TP of the OT therefore disappears. This factor increases the probability of a change in leadership. However, incumbents still have advantages in terms of resources (e.g., capital, general knowledge on how to improve the productivity of a technology, etc.), which help them defend their leadership and partly offset the probability of a change in leadership. Therefore I hypothesize that if the BP of the NT is the same as and higher than level B, the probability of a change in industrial leadership from an incumbent leader to a latecomer is little higher than the baseline probability of leadership changes.

Below is the overall hypothesis on the relationship between the BP of the NT and changes in leadership in an industry from incumbents to latecomers:

- 1) When the basic productivity (BP) of the new technology (NT) is as low as any firm using *the old technology (OT)* doesn't adopt the NT at the time of the arrival of the NT, the probability of a leadership change is the same as the baseline of leadership change.
- 2) When the BP of the NT is as high as to make some of the firms in the industry adopt the NT but not as high as to make all the firms adopt the NT, the probability of a change in industrial leadership from an *incumbent leader to a latecomer* is "*substantially*" higher than the baseline probability of a leadership change due to the incumbent trap. Furthermore, within this range, a higher BP of the NT is more likely to lead to a change in industrial leadership.
- 3) Lastly, when the BP of the NT is as high as to make all the firms adopt the NT, which means the BP of the NT is the same as and above the highest productivity of the old technology achieved by a firm in the industry, the probability of a change in industrial leadership is "*little*" higher than the baseline probability of a leadership change.

Below is a diagram that describes the hypothesis.

Figure 1. A graphical description of the hypothesis



To test the hypothesis, I develop a formal simulation model from a perspective of evolutionary economics. In evolutionary economics, simulation analysis is a way to build a formal model. As appreciative theorizing and case studies on changes in industrial leadership and catch-up by latecomers are increasing, the need of formal modeling of such narrative explanations is increasingly required. Landini et al. (2015) replicate five different patterns of leadership changes and to explore their determinants. In their model, the incumbent trap serves as one of the four determinants. However, because the purpose of the model is to replicate five different patterns of leadership changes, the model is too complicated to solely explore the role of the incumbent trap in leadership change. In addition, in their modeling of the incumbent trap, one of the most fundamental technological conditions that are associated with incumbent trap is missed: the level of the initial performance of new technology. Malerba et al. (2007) analyze the role of experimental users and diverse preferences when an innovation appears. They assume that the new technology is initially inferior to the established technology which has been mastered by incumbents. By contrast, my study allows various initial performance level of new technology, compared with the highest performance level of the established one. Kim and Lee (2003) explores how large, diversified firms as a latecomer catch up with the small, specialized incumbent firms in the DRAM industry in the late 20 century. They identifies some conditions of catch-up in terms of technological regime. Lee et al. (2013) explore the relationship between catch-up strategies proposed by Lee and Lim (2001) and demand conditions.

### 3. The Model

My model is a simplified and modified version of the evolutionary model of Nelson and Winter (1982). R&D activity (innovation and imitation) is removed. Instead, learning-by-doing is added. The model starts with one production technology, and a new technology is introduced in a certain period of the simulation run when the gaps in market share among the firms are sufficiently widened.

The model is of an industry in which several firms employ a production technology to produce a single homogeneous product. Market shares of the firms are determined by productivity competition. Firm productivity of a specific technology is the sum of basic productivity (BP) that is exogenously given at the time of the arrival of the technology and additional productivity through learning-by-doing of the firm and the industry (individual and collective learning-by-doing, respectively). After a new technology appears, firms choose old or new technology in their search for more profit.

For simplicity, there are some assumptions:

- All the firms have the perfect information on the basic productivity and productivity increment by collective learning-by-doing of a technology
- No cost occurs when a firm adopts a new technology.
- Firms takes Cournot strategy: “a firm picks a target capital stock on the basis of a correct appraisal of the industry demand elasticity and a belief that the other firms will hold output constant.” (Nelson and Winter 1982: 284)
- New technology is given to firms exogenously. No R&D is conducted by firms themselves.
- No new entry and exit

Formally, the model has the following structure.

$$Q_{it} = A_{ijt}K_{it} \quad (1)$$

The output of firm  $i$  at time  $t$  equals its capital stock times the productivity of technology  $j$  it is employing.

The productivity of technology  $j$  of firm  $i$  at time  $t$  ( $A_{ijt}$ ) is the sum of three factors: (1) the BP that is exogenously given at the time of the arrival of technology  $j$ , which the firm is employing, ( $BP_j$ ), (2) the productivity increment obtained through the collective learning by doing of (or spillover among) all the firms adopting technology  $j$  ( $CP_{jt}$ ), and (3) the increase in the productivity of firm  $i$  through its learning by doing ( $IP_{ijt}$ ). The second and third components are stochastic functions of the cumulative amount of collective and individual output, respectively.

$$A_{ijt} = (BP_j + CP_{jt}) + IP_{ijt} \quad (2)$$

$BP_j + CP_{jt}$  is common to all the firms employing the same technology, and each firm has its own value of  $IP_{ijt}$ .

$$BP_{j=new\ tech.} = \alpha \times \max_i(A_{i(j=OT)t}) \quad (3)$$

I define the BP parameter, the alpha( $\alpha$ ).  $\alpha$  is the ratio of the BP of the NT to the highest productivity of the OT achieved by a firm in the industry, which is normally achieved by the firm with the largest market share. When an NT appears in the industry in period t, its BP is exogenously given and is equal to  $\alpha$  times the highest (best practice) productivity level of the OT in the industry in period t.

$$CP_{jt} = \max(CP_{jt}, \widetilde{CP}_{jt}), \text{ where } \widetilde{CP}_{jt} \sim N(\lambda_c(\sum_t Q_{jt}), \sigma_c), \text{ with } \lambda_c(\sum_t Q_{jt}) = \beta(\sum_t Q_{jt})^{\alpha_1} \quad (4)$$

$\sigma_c$  has a form that ensures that the standard deviation of  $\widetilde{CP}_{jt}$  has a certain percentage of  $\lambda_c(\sum_t Q_{jt})$ . Here,  $\widetilde{CP}_{jt}$  is a random variable that is the result of the collective learning by-doing of (or spillover among) all the firms adopting the same technology.

$$IP_{ijt} = \max(IP_{ijt}, \widetilde{IP}_{ijt}), \text{ where } \widetilde{IP}_{ijt} \sim N(\lambda_I(\sum_t Q_{ijt}), \sigma_c), \text{ with } \lambda_I(\sum_t Q_{ijt}) = \gamma(\sum_t Q_{ijt})^{\alpha_2} \quad (5)$$

$\sigma_I$  has a form that ensures that the standard deviation of  $\widetilde{IP}_{ijt}$  has a certain percentage of  $\lambda_I(\sum_t Q_{ijt})$ . Here,  $\widetilde{IP}_{ijt}$  is a random variable that is the result of the individual firm's learning by-doing.

$$Q_t = \sum_i Q_{it} \quad (6)$$

$$P_t = \frac{R}{Q_t} \quad (7)$$

“Industry output is the sum of individual firm outputs. Price is determined by industry output, given the fixed size of the market demand, R.” (Nelson and Winter 1982)<sup>1</sup>

$$\pi_{it} = P_t A_{ijt} - c \quad (8)$$

“The profit on capital of that firm equals product price times output per unit of capital, minus production costs (including capital rental) per unit of cost.” (Nelson and Winter 1982: 285)

“A firm's desired expansion or contraction is determined by the ratio of price to production cost,  $P/(c/A)$  – or equivalently, the percentage margin over cost – and its market share. But a firm's

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<sup>1</sup> This description of the model is borrowed directly from Nelson and Winter (1982) because this model piece is (almost) identical to that of theirs. You can find more direct quotations in the following description of the model for the same reason. All of them will be rephrased in a later version of this paper.

ability to finance its investment is constrained by its profitability, which is affected by its revenues and production costs.” (Nelson and Winter 1982: 285)

$$K_{i(t+1)} = I\left(\frac{P_t A_{i(t+1)}}{c}, \frac{Q_{it}}{Q_t}, \pi_{it}, \delta\right) \times K_{it} + (1 - \delta)K_{it} \quad (9)$$

“Here,  $\delta$  is the physical depreciation rate, and the gross investment function  $I(\cdot)$  is given by:” (Nelson and Winter 1982)

$$I(\rho, s, \pi, \delta) = \max\left[0, \min\left\{\left(1 + \delta - \frac{(2-s)}{\rho(2-2s)}\right), f(\pi)\right\}\right],$$

$$\text{where } f(\pi) = \delta + \pi \text{ for } \pi \leq 0 \text{ or } \delta + 2\pi \text{ for } \pi > 0 \quad (10)$$

An NT is exogenously introduced in an industry at period  $t^*$ , which will be loosened in Section 5.1. In that period and afterward, a firm evaluates the NT to determine whether to adopt it or not. If the expected productivity of the NT is higher than that of the OT, then that firm adopts the NT. Otherwise, the firm keeps using the OT. Formally,

$$\text{If } E(A_{i(j=NT)t^*+1}) \geq E(A_{i(j=OT)t^*+1}),$$

firm  $i$  adopts the NT. Otherwise, firm  $i$  maintain the OT,

$$\text{where } E(A_{i(j=NT)t^*+1}) = A_{i(j=NT)t^*+1} = BP_{j=NT} + CP_{(j=NT)t^*+1} \text{ and}$$

$$E(A_{i(j=OT)t^*+1}) = A_{i(j=OT)t^*+1} = BP_{j=OT} + CP_{(j=NT)t^*+1} + IP_{i(j=OT)t^*+1}. \quad (11)$$

A firm’s expected productivity of the NT does not include the increase in productivity through that firm’s learning by doing in the following period ( $IP_{i(j=NT)t^*+1}$ ). The reason is that the firm has no output using the NT before adopting the NT. For a similar reason,  $CP_{(j=NT)t^*+1} = 0$ .

Once a firm adopts the NT, its capital stock ( $K_{it}$ ) is used with the NT to produce the same homogeneous product. I assume that the adoption of the NT is not reversible.

## 4. Simulations

### 4.1. The Settings

The simulation starts with eight firms and one technology. The BP of the OT ( $BP_{j=OT}$ ) is set to a positive real number. The eight firms’ initial values of cumulative outputs are equally set to 0, and the initial values of their individual learning by doing of the OT are also equally 0. As a result, all the firms have the same initial value of productivity ( $A_i$ ). All the firms have the same initial value of capital stocks ( $K_i$ ). Thus, with the same productivity ( $A_i$ ) and capital stocks ( $K_i$ ), all the firms’

outputs ( $Q_{i(t=1)}$ ) and market shares in period 1 are also the same each other.

An NT appears in period 150. The simulation ends after period 300.

All the parameter settings are provided in Appendix.

## 4.2 Results

How do the incumbent trap and therefore leadership changes occur? How do the effects of the incumbent trap on leadership changes vary according to the values of  $\alpha$ ? When they occur, which firm assumes the leadership?

To answer such questions, we begin with single runs of the model over time by the value of the parameter.

### 4.2.1 Single runs by the value of $\alpha$

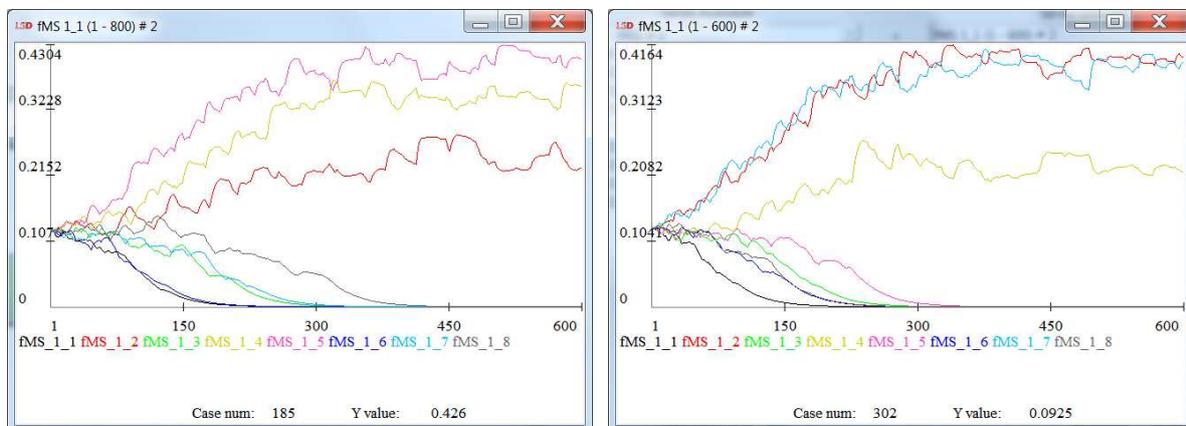
a) When  $\alpha$  is low ( $0 \leq \alpha \leq 0.7$ )

- When  $\alpha=0$

I present cases in which no new technology appears during the simulation as a bench mark; this corresponds to setting  $\alpha$  to 0.

Figure 2. Market share dynamics with  $\alpha=0$

(a) A case in which a change in leadership does not occur. (b) A case in which leadership change occurs.



The typical market share dynamics when a change in leadership does not occur is presented in Figure 1-(a). With the identical initial values of all the parameters among the firms, the market shares of all

eight firms start at 12.5%, respectively. The market shares of the firms diverge over time. While three firms gain considerable market shares, the market shares of the remaining five firms shrinks to 0%. The reason why market shares diverge is that an increase in productivity through firm  $i$ 's learning by doing ( $IP_{ijt}$ ) contains a random variable that is the result of the individual firm's learning by doing. Thus, the firms' productivities ( $A_{it}$ ) diverge, and consequently, their capital stocks and output. Eventually evolutionary winners and losers emerge in the industry. No NT is introduced in period 150 so that no substantial market shake up occurs after that period. That is, the industry leader in period 150 (Firm 5, pink line in Figure 1-(a)) maintains its leadership until the end of the simulation, except for a temporal reverse with the second largest firm (Firm 4, yellow line) around period 330.

Figure 1-(b) presents a case in which a change in leadership occurs. No NT appears in period 150, when Firm 7 (light blue line) is the industry leader. However, at the end of the simulation run, the leader is Firm 2 (red line). The market shares of the two firms competing for the largest market share turn over and over all through the simulation run. Thus, the industry leader changes depending on the period at which the industry leader at the moment is checked. For example, around period 300, the leader is Firm 2 (red line), whereas around 450, the leader is Firm 7 (light blue line). Thus, it is hard to say that leadership change when no NT appears is a substantial change in leadership from an incumbent leader to a latecomer, which will be clearly reproduced with higher values of  $\alpha$  in the latter part of this section.

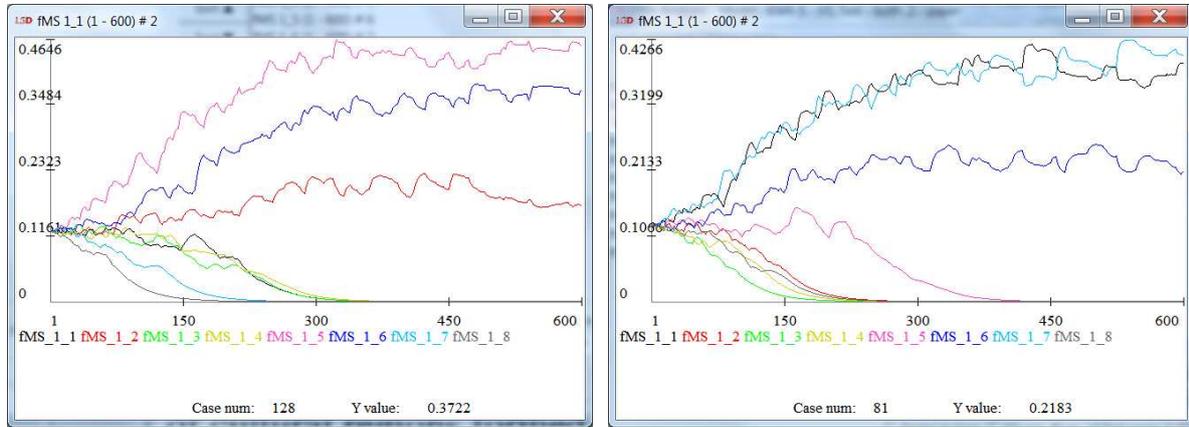
Without the appearance of an NT (equivalent to  $\alpha = 0$ ), a change in leadership usually does not occur in my model. A specific value of the frequency of leadership change is presented in Section 5.2.2.

### - When $\alpha \leq 0.7$

While  $\alpha$  is increased to around 0.7 by 0.1, the patterns of leadership change that are obtained are the same as those of when  $\alpha = 0$ . That is, a change in leadership usually does not occur, and rare cases of a change in leadership present many turnovers in market shares between the top 2 firms all throughout the simulation runs. Figure 2 presents typical examples of market share dynamics when an NT with an  $\alpha$  of 0.7 appears in period 150. An  $\alpha$  of 0.7 means that an NT appears with a BP of 70% of the highest productivity level obtained with the OT in the period when the NT appears. That is,  $BP_{j=NT.} = 0.7 \times \max_i(A_{i(j=OT)}(t=150))$ . The occurrence of leadership change in Figure 2-(b) may seem to result from the appearance of an NT in period 150. However, this is not the case. The market share dynamics in Figure 2-(b) are quite similar with those in Figure 1-(b), in which a leadership change occurs without the appearance of an NT. The latter part of this subsection show that market share dynamics are totally different when  $\alpha$  is high so that a leadership change occurs with the appearance of an NT and consequently the incumbent trap phenomenon.

Figure 3. Market Share Dynamics when basic productivity parameter ( $\alpha$ ) = 0.7

(a) A case when a change in leadership doesn't occur. (b) A Case when a change in leadership occurs.



**b) When  $\alpha$  is high ( $0.8 \leq \alpha < 1.0$ )**

**- When  $\alpha = 0.8$**

With BP parameter of 0.8, which means the BP of the NT is 80% of the highest productivity level of the old technology in the period when the NT appears ( $BP_{j=new\ tech.} = 0.8 \times \max_i(A_{i(j=OT)}(t=150))$ ), an incumbent trap phenomenon and thus a leadership change start to occur. Figure 3-(a) presents market share dynamics and corresponding productivity dynamics of a single example when incumbent trap and thus leadership change occur. In period 150 when the NT appears, 2 firms with the lowest market shares (Firm 3 and 7: green and light blue lines, respectively, in Figure 3-(a)) adopt the NT while the others doesn't. Since then, the market shares of the two NT-adopting firms catch-up with and eventually surpass the firm with the largest market share. Note that the new leader is the firm whose market share is larger between the two NT-adopting firms, Firm 3 here. Behind the scene of the competition in market share, NT-adopting firms surpass the OT-keeping firms in terms of productivity,  $A_{it}$ . The reason is that with the same increment in accumulative output, while it is hard to add to productivity with “matured” OT, it is much easier to do so with “young” NT. This concept is reflected in the diminishing return functions of collective/individual learning-by-doing (see Eqs. (4) and (5) in Section 4. The Model). A firm with a higher productivity has higher actual markup and profits so that its investment rate is higher than others and thus its capital stock increases in a higher rate than others. With higher increment in productivity and capital stock than others, the firm increases its output and market share quickly. Some of the firms which didn't adopt the NT in period 150 when the NT appeared adopt the NT lately. Firm 5 and 6 (pink and blue lines, respectively, in Figure 3-(a)) are this case in the example of Figure 3-(a). Note that they were the firms with the third and fourth lowest

market shares when the NT appeared. Meanwhile, top 4 firms in market share when the NT appears don't adopt the NT until the end of the simulation run. Therefore, I suspect the higher a firm's market share is, the later the firm adopts the NT. The reason is that given that a firm with a higher market share normally has a higher total productivity (TP) of the OT when the NT appears, the higher a firm's total productivity of the OT is, the later the expected productivity of the NT surpasses the firm's total productivity of the OT. This is an incumbent trap phenomenon: in order to enjoy higher productivity with the OT, the incumbents defer adopting the NT while the latecomers adopt it. As a result, the latecomers accumulate output with the NT first and go ahead of the incumbents on the learning curve of the NT, which eventually results in a change in leadership from the incumbents to the latecomers. Table 1 summarizes the periods when the firms adopt the NT in the example of Figure 3-(a) and changes in market share between when the NT appears (t=150) and when the simulation run ends (t=300).

Figure 4. The Dynamics of Market Shares and Productivities (BP parameter = 0.8)

(a) When a change in leadership occurs.

(b) When a change in leadership doesn't occur.

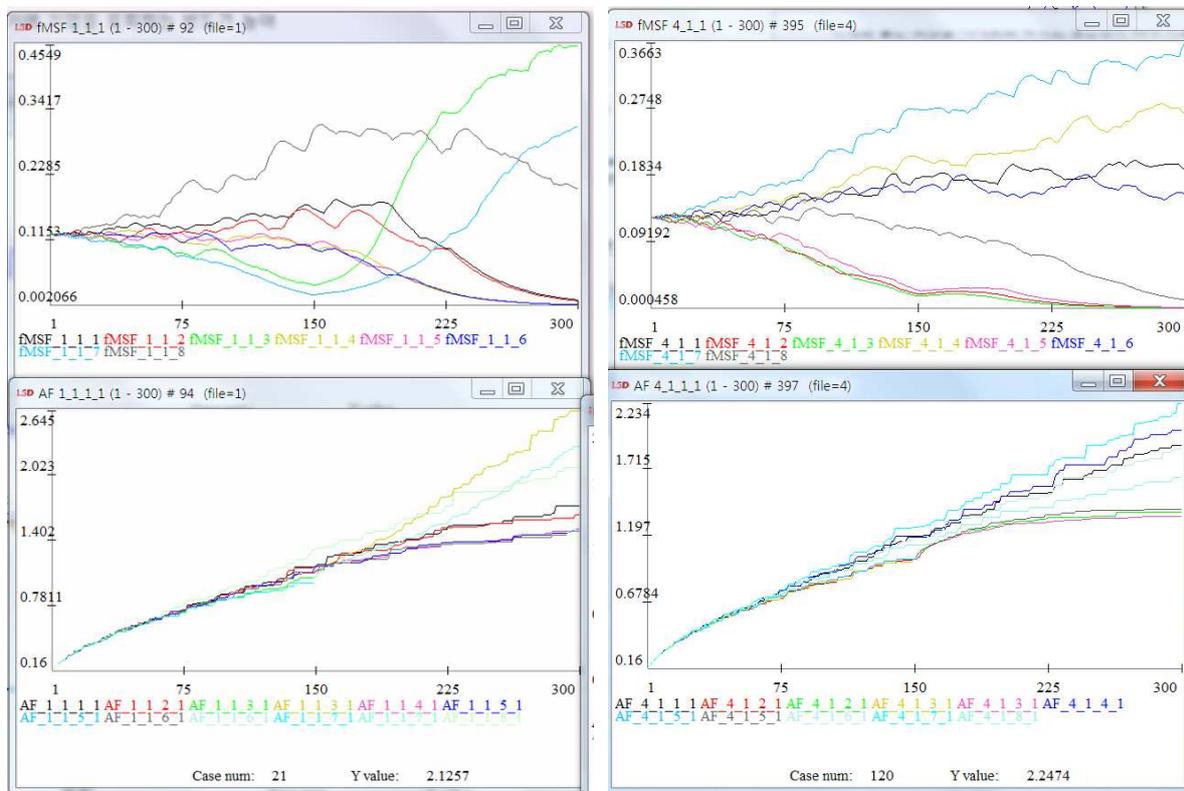


Table 1. The relationship between the order of NT adoption and the market shares when the NT appears

| Firm ID | Market Share (MS) ranking in Period 150 when the NT appears | Period when adopting the NT | MS ranking in Period 300 when the simulation run ends | A Change in MS Ranking |
|---------|---|-----------------------------|---|------------------------|
| 8       | 1 <sup>st</sup>   | don't adopt                 | 3 <sup>rd</sup>                                       | -2                     |
| 1       | 2 <sup>nd</sup>   | don't adopt                 | 4 <sup>th</sup>                                       | -2                     |
| 2       | 3 <sup>rd</sup>   | don't adopt                 | 5 <sup>th</sup>                                       | -2                     |
| 5       | 4 <sup>th</sup>   | don't adopt                 | 6 <sup>th</sup>                                       | -2                     |
| 4       | 5 <sup>th</sup>   | t=153                       | 7 <sup>th</sup>                                       | -2                     |
| 6       | 6 <sup>th</sup>   | t=153                       | 8 <sup>th</sup>                                       | -2                     |
| 3       | 7 <sup>th</sup>   | <b>t=150</b>                | 1 <sup>st</sup>                                       | <b>+6</b>              |
| 7       | 8 <sup>th</sup>   | <b>t=150</b>                | 2 <sup>nd</sup>                                       | <b>+6</b>              |

Figure 3-(b) presents a single example in which despite the lowest 3 firms adopting the NT, leadership changes doesn't occur. The NT-adopting 3 firms catch up with the others, which keep using the OT, to some extent in terms of productivity due to the quick increase in the productivities of the NT-adopting firms. However, that is not enough to surpass any of the 5 OT-using firms. As a result, the 3 NT-adopting firms gain some market shares temporarily right after adopting the NT but eventually lose them again with time.

**- When  $\alpha \geq 0.8$**

As BP parameter increases from 0.8 to 0.85, 0.9, and so on, the number of the firms which adopt the NT in period 150, when the NT appears, increase. The reason is that the higher the BP of the NT is, the more firms perceive the advantage of the NT over the OT in terms of the expected productivity in the period when the NT appears. Therefore, with higher values of BP parameter, firms with higher market shares adopt the NT in period 150. Table 2 shows the average number of the NT adopters in period 150 by BP parameter. When the parameter is 0.99, 7 firms out of the 8 firms adopt the NT in period 150.

Table 2. The average number of the NT adopters in period 150 by BP parameter

(To be added)

In addition, the firms which didn't adopt the NT in period when the NT appears more quickly adopt the NT as BP parameter is higher. The reason is that the expected productivity of the NT more quickly

surpasses the expected productivity of the OT of the firms which didn't adopt the NT in period when the NT appears. Figure 4 and Table 3 shows a single example of this case with BP parameter of 0.9. Four firms adopt the NT in period 150, and 2 firms do so only a few periods later.

Figure 5. The Dynamics of Market Shares (BP parameter = 0.9)

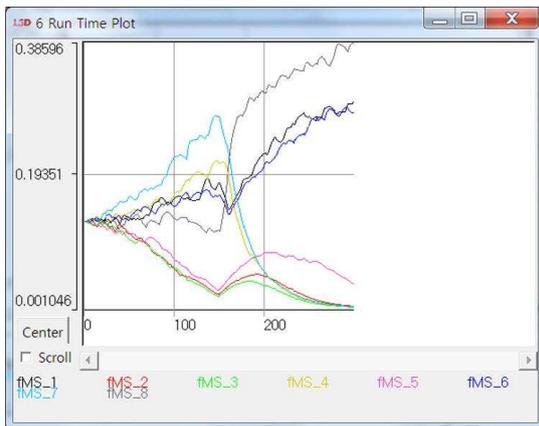


Table 3. The relationship between the order of NT adoption and the market shares when the NT with  $\alpha = 0.9$  appears

(To be added)

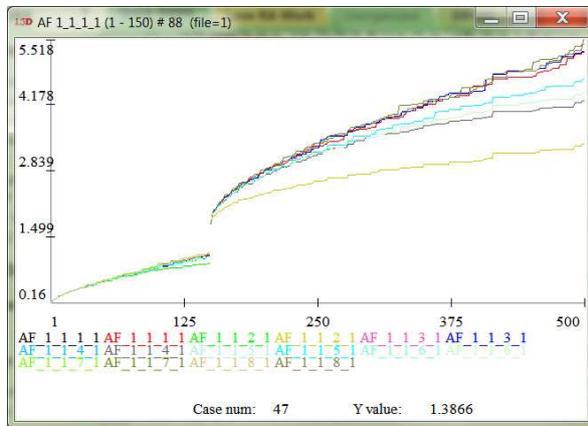
**c) When  $\alpha$  is too high ( $1.0 \leq \alpha \leq 1.5$ )**

If BP parameter becomes 1.0 and over, patterns of competition in market share changes again. BP parameter of 1.0 and over means the BP of the NT is the same as or higher than the highest productivity level with the old technology when the NT appears. That is,  $BP_{j=NT} = (1.0 \text{ and over}) \times \max_i(A_{i(j=OT)(t=150)})$ . Therefore, with such values of BP parameter, all the firms adopt the NT immediately in the period when the NT appears ( $t = 150$ ).<sup>2</sup> Their initial productivities of the NT are equal to each other. Formally,  $A_{i(j=NT)(t=150)} = BP_{j=NT}$  for all  $i$ , which means the difference in productivity with the OT among firms disappears. This “reset” is advantageous to the firms with lower market shares, assumed to be latecomers in the model, and disadvantageous to the firms with higher market shares, assumed to be incumbents in the model.

<sup>2</sup> I assume that when the expectation of the productivity of the NT is the same as that of the OT, a firm replaces the OT with the NT. The result has no substantial difference from that of the reverse case.

Figure 6 presents a single example of the “reset” in productivities in period 150.

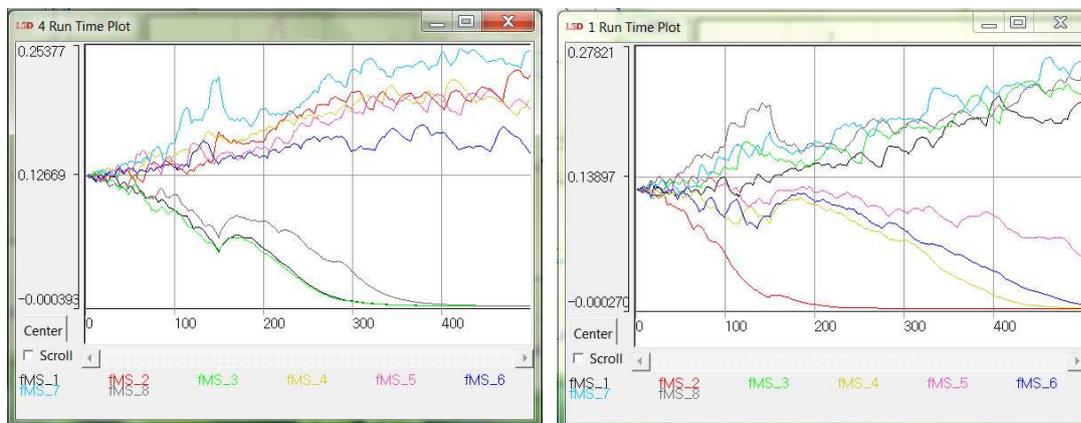
Figure 6. All the firms have the same productivities with the NT in period 150.



Incumbents maintain their advantages in capital stocks because the model assumes that the existing capital is available with the NT without any loss when changing technologies. Therefore, the impact of “reset” in productivity is reduced, which helps the leaders to defend their leadership. How much it helps, or the frequency of a change in leadership, will be addressed in Section 4.2.2. Hypothesis Analysis. I present single simulation runs of the two typical cases with BP parameter of 1.5 in Figure 7. Figure 7-(a) presents a case in which the incumbent’s leadership is maintained even though the leader’s market share shrunk temporarily right after period 150, when the NT appeared. Figure 7-(b) presents a case in which the incumbent leader fails to defend its leadership, making many turnovers in market share with the 2<sup>nd</sup> and 3<sup>rd</sup> largest firms after period 150.

Figure 7. Market share dynamics when BP parameter is 1.5

- (a) A change in leadership occurs      (b) A change in leadership doesn’t occur.



Regardless of whether the leadership change occurs or not, the common feature is the existing order

of market shares doesn't change much after the NT is introduced even though the gap between the leader and the second-tier firms are substantially reduced.

Now, I can generalize the conditions under which an incumbent trap and thus a change in leadership occur. A change in leadership occurs when alpha is large enough to attract the firms with market shares large enough to quickly move ahead on the learning curve of the NT so that at least one of them surpasses the OT-using market leader in terms of productivity, which is "trapped" with the OT. This is a change in industrial leadership by incumbent trap phenomenon. With low or too high values of alpha, leadership change can also occur. Yet this type of the change bear no relation to incumbent trap phenomenon. Instead, those changes are associated with naturally repeated turnovers in productivities due to randomness in learning-by-doing.

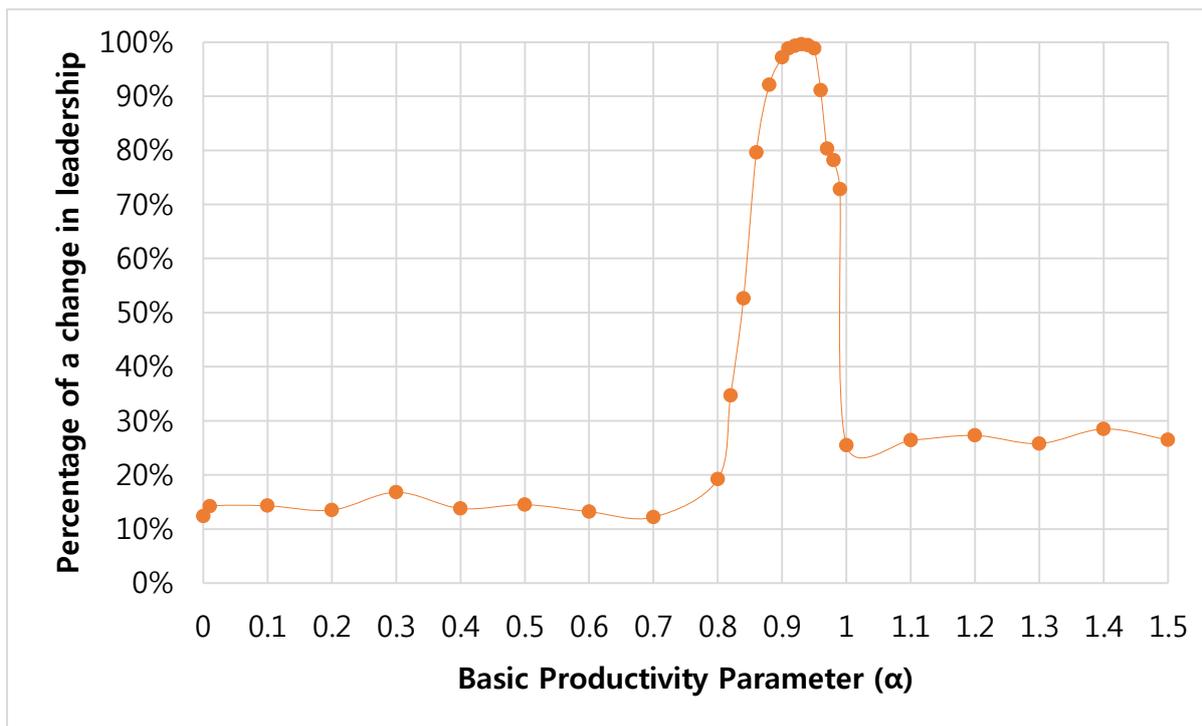
#### 4.2.2 Hypothesis analysis

Now, I present the frequency of a change in leadership by the value of BP parameter. I change the basic productivity parameter ( $\alpha$ ), from 0 to 1.5 by an interval of 0.1. This interval is reduced to 0.01 in some ranges for detailed analysis on interesting results. For each basic productivity parameter ( $\alpha$ ), simulations are iterated 1,000 times. The values of the other parameters are found in Appendix.

The occurrence of a change in leadership is decided by whether the firm with the largest market share at the end of the simulation ( $t=300$ ) is different from the firm with the largest market share at the emergence of new tech. ( $t=150$ ). If different, we can say a change in industrial leadership from the incumbent leader to a latecomer after the new technology is introduced in the industry. You can notice I assume that the reverse order of the market share in the period when the NT appears is the order of the lateness of the entering the industry. This assumption can be justified given that, in the reality, the order of market share roughly reflects the order of industry entry.

Figure 8 presents the frequency of a change in leadership from a leader to a latecomer after the NT is introduced in period 150.

Figure 8. The Frequency of a change in leadership from an incumbent leader to a latecomer after the NT is introduced in period 150 with the values of the BP parameter



When the BP parameter is below 0.8, which means new technology appears with its basic productivity of the 80% of the highest productivity level of the old technology in the period when the NT appears, the frequency of leadership change is about 15%, which can be referred to as a baseline probability of a leadership change. The frequency surges as the parameter increases above 0.8 and reaches the peak of 99.6% at the BP parameter of 0.93. After that, the frequency drops to about 25% until the alpha reaches 1.0, and this frequency is roughly maintained with the alpha higher than 1.0. These results roughly support the hypothesis. In particular, with alpha between .8 and 1.0 a change in leadership is more likely to occur than with other values of alpha. As analyzed in Sub-section 4.2.1.b) When  $\alpha$  is high ( $0.8 \leq \alpha < 1.0$ ), the reason is that incumbents are trapped with the OT so that they keep using the OT at least a few periods longer than the latecomers which adopt immediately the NT when the NT appears.

However, the inverted U-shaped relationship between 0.8 and 1.0 of alpha is not expected. Figure 9 presents the abstracted comparison between the hypothesis and the results of simulation test. The reason of the inverted U-shaped relationship is that, beyond a certain point in this range (alpha = 0.93 here), a higher BP of NTs prompts incumbent leaders to adopt NTs not long after latecomers do. Thus, when the leaders adopt the NT, their initial productivities of the NT lag only a little behind the productivities of the latecomers who adopted it first. The small productivity lag is overcome by the larger capital of the leaders before long because the leaders accumulate output quickly due to their higher capital stocks. As a result, they catch up with the early adopters before long. The leaders

increasingly succeed in leadership defense on the right-hand side of the inverted U-shaped curve. Table 4 presents the average of the period lags in the leaders' adoptions and of the initial productivity gaps of the leaders with the values of alpha. Beyond alpha = 0.93, the adoption period lags and the initial productivity gaps of the leaders start to decrease.

Figure 9. Hypothesis vs. simulation results

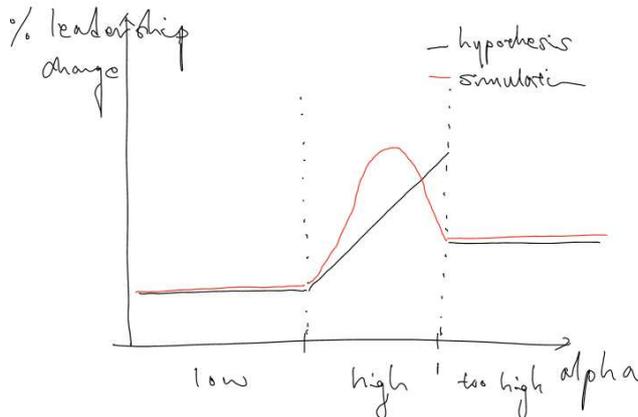


Table 4. The average of the period lags in the leaders' adoptions and of the initial productivity gaps of the leaders with the values of alpha

(To be added)

When alpha is too high, or 1.0 and over, the frequency of leadership change is much lower than when alpha is high, or between 0.8 and 1.0. This result means “too good” NT (=too high BP of the NT) does not necessarily help in leadership change from the leader to the latecomers. The frequency of too high alpha is only about 10%p higher than when alpha is low, or below 0.8. This value is substantially lower than the frequencies of a leadership change when alpha is 0.8 and 1.0. The larger capital stocks of the incumbents substantially helps to defend their positions between on after the NT is introduced despite the disappearing of their advantage in productivity with the OT.

## 5. Discussion

### 5.1 Endogenous innovation

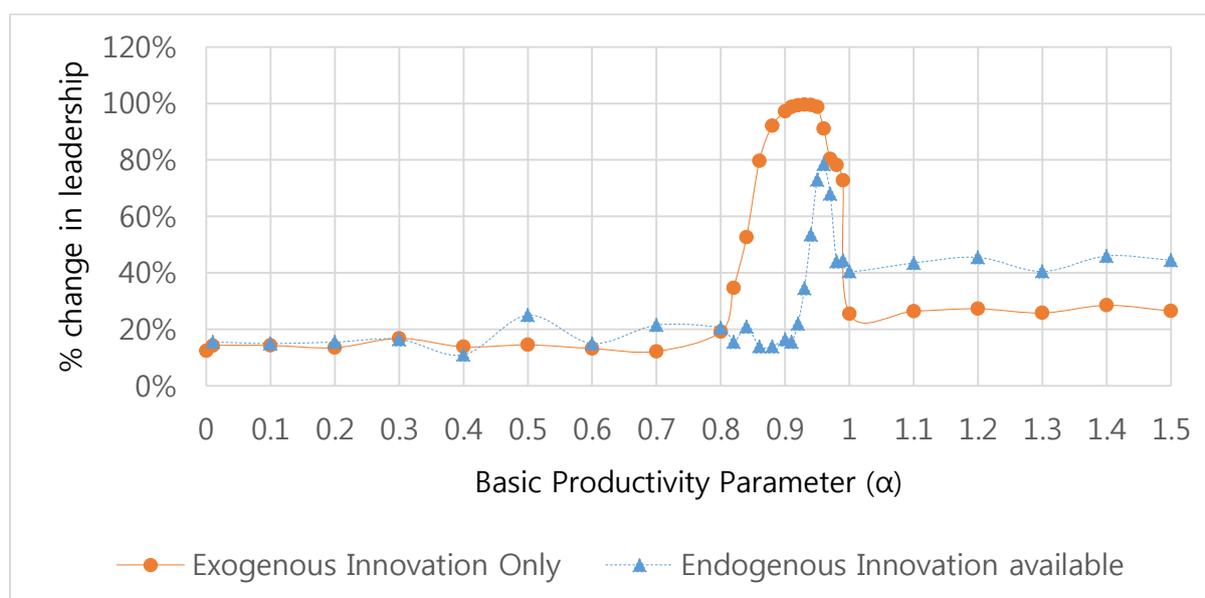
The current model assumes that new technology is exogenously given to the firms. This sub-section

explores a case in which new technology is “endogenously” available by the R&D of the firms. Lee and Malerba (2015), which provides an appreciative theory of my formal simulation model, suggest without any verification a narrative conjecture on the difference between exogenous and endogenous innovations in the effects on a change in industrial leadership from an incumbent leader to a latecomer. My formal simulation model enables us to test their conjecture. I add a model piece of a firm’s R&D to the current model and conduct an experiment to compare its frequency of a leadership change with that of the original model in which a firm’s R&D doesn’t included, which means innovation is only given exogenously to the firms. Below is the details of the model pieces added for this test.

(To be added.)

The simulation results support the conjecture of Lee and Malerba (2015). Both types of innovation have similar patterns of frequencies of a leadership change with the values of the BP parameter. The additional finding is that when a firm does R&D activities, a change in industrial leadership is less likely to occur than when innovation is only exogenously given to the firms. Figure # presents this comparison.

Figure #. A comparison between the effects of endogenous and exogenous innovations on a leadership change (To be revised)



Incumbents tend to have higher R&D capabilities due to their higher capital stocks. Therefore, the

outcomes of their R&D activities tends to higher than those of the latecomers; as a result, incumbents more easily defend their leadership than when innovation is only given exogenously.

## 5.2 A driving force of leadership change

On the left side of the inverted U curve, as the BP parameter gets higher, the more firms adopt the NT in period 150, when the NT appears, and the more frequently leadership change occurs. With these facts, you may suspect the number of the firms that adopt the NT in period 150 determines the likelihood of the occurrence of leadership change. It seems that this is not the case: Instead, the actual cause is that a higher value of the BP parameter allows a firm with a larger market share to adopt the NT in period 150. In other words, even when only one firm adopts NT in period 150, if the firm has enough market shares, the firm is able to catch up with and eventually surpass all the other firms. Figure 10-(b) presents this case. In this case, the BP parameter is 0.88. In period 150 when a NT appears, Firm 3 (green line), the firm with the lowest market share, is the only firm which adopts the NT. At that moment its market share is 3.2%. Figure 10-(a) presents a case in which, with BP parameter of 0.88, two firms adopt the NT in period 150, but leadership change doesn't occur. Their market shares are about 1%, respectively in period 150. The comparison of the two cases implies that the real driving factor of leadership change is not the number of the NT adopting firms in period when the NT appears but the size of the market share of the largest firm among the NT adopters in that period. Therefore, the reason why a change in leadership is more likely to occur with higher values of BP parameter is that higher BP parameters are more likely to attract firms with market shares large enough to manage to take the leadership.

Figure 10. The number of the NT-adopters and leadership change

(a) Two NT-adopting firms fail to take the leadership (b) One NT-adopting firm succeeds in doing so.

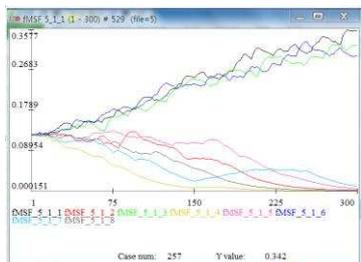


### 5.3 Which firm takes the leadership?

When a change in leadership occur from an incumbent leader to a latecomer with the NT, which firm takes the leadership?<sup>3</sup>

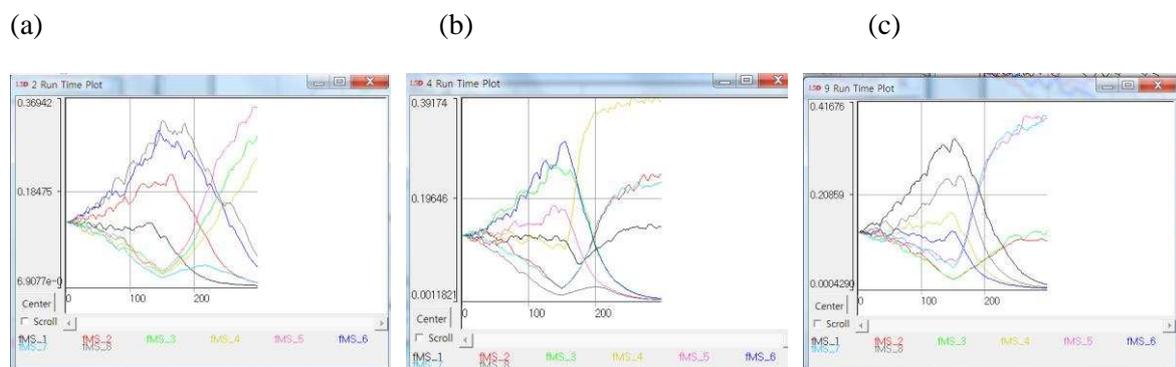
Among the firms which adopt the NT in the period when the NT appears, “usually” the firm with the largest market share. In Figure 11-(a), Firm 5 (pink line) has the largest market share among the firms which adopt the NT when the NT appears ( $t=150$ ) and becomes a new market share leader at the end

<sup>3</sup> A change in leadership occurs not between NT- and OT-using firms but between OT using firms despite the appearance of the NT. For example, with a low value of alpha, some firms with the lowest market shares adopt the NT but they fails to catch up with the incumbent leader. Instead, a new leader results from many turnovers among the OT using firms with the largest market shares (e.g. top 3 firms). Figure below presents a single run of such a case.



of the simulation run. A firm which adopts the NT a few periods later than the firms which adopt the NT immediately when the NT appears also can become a leader. The reason is that its large enough capital stocks serves as a power to compensate the lateness in the NT adoption by quickly accumulating output with the NT. As a result, it surpasses the earlier adopters in productivity before its size of capital stock is reversed by the early adopters. Figure 11-(b) is this case. However, if the capital stock of a firm which adopts the NT a few periods later than the firms which adopt the NT immediately when the NT appears is not large enough to do so, the new leadership has a mixed result between the firm whose market share is the largest among the firms adopt the new tech immediately when the NT appears and the firm who adopted a bit later but has a larger capital stock than the former firm. Figure 11-(c) presents this case. Firm 7 (light blue line) is a firm whose market share is the largest among the firms which adopt the NT in period 150. Firm 5 (pink line) is a firm which adopts the NT in period 153. Firm 5 is late than Firm 7 in the NT adoption by 3 periods but the firm had large capital stocks at the time of its adoption. You can see the two firms keep competing the leader's position until the end of the simulation run.

Figure 11. Single runs to explore which firm becomes a new leader (BP parameter = .85)



If we regard capital stock as a kind of capability that is necessary to take advantage of a technology, the simulation result implies that a firm's capability matters: among the NT adopters, the higher capability a firm has, the more likely the firm takes the leadership. What if the existing capability is not available with the new tech? In other words, what if the new tech is a competence-destroying technology? Then the new leader is not anticipated by the accumulated capability or competence with the OT. In the same vein, the new leader would not always be the firm whose market share is the largest among the first NT adopters.

## **6. Conclusion**

By building a Nelson–Winter-like model, this study explores the conditions under which an incumbent trap and a change in industrial leadership occur in terms of the basic productivity of the new technology. If the BP of an NT is low, a leadership change occurs with a low frequency. If it is too high, the frequency is moderate. If it is high, the leadership change frequency is high. The incumbent trap found with high BPs of the NT has an inverted U-shape. This is the first study to find the shape of the incumbent trap in a change in industrial leadership from an incumbent to a latecomer when a new technology appears.

The findings of the study gives us a better understanding on why some new technology results in an incumbent trap and thus a change in leadership in an industry, while others don't. In addition, the study found a new leader is usually the firm whose market share is the largest among the firms which adopt the NT first. This implies that an appropriate technological change (high alpha) in the industry and a firm's capability (capital stocks here) are both important for leadership change by latecomers.

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## **Appendix**

(To be added)