

# Discrete innovation, continuous improvement, and competitive pressure

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## Abstract

Does competitive pressure foster innovation? In addressing this important question, prior studies ignored a distinction between *discrete innovation* aiming at entirely new technology and *continuous improvement* consisting of numerous incremental improvements and modifications made upon the existing technology. This paper shows that distinguishing between these two types of innovation will lead to a much richer understanding of the interplay between firms' incentives to innovate and competitive pressure. In particular, our model predicts that, in contrast to previous theoretical findings, an increase in competitive pressure measured by product substitutability may *decrease* firms' incentives to conduct continuous improvement, and that an increase in the size of discrete innovation may decrease firms' incentives to conduct continuous improvement.

A unique feature of this paper is its exploration of the model's real-world relevance and usefulness through field research. Motivated by recent declines in levels of continuous improvement in Japanese manufacturing, we conducted extensive field research at two Japanese manufacturing firms. After presenting our findings, we demonstrate that our model guides us to focus on several key changes taking place at these two firms; discover their interconnectedness; and finally ascertain powerful underlying forces behind each firm's decision to weaken its investment in traditional continuous improvement activities.

**Keywords:** Competitive pressure, continuous improvement, discrete innovation, field research, location model, product substitutability, small group activities, technical progress.

**JEL classification numbers:** L10, L60, M50, O30

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# 1 Introduction

Technical progress consists of innovative activities aiming at entirely new products and processes, and numerous minor improvements made upon the existing technology (see, for example, Kuznets, 1962; Rosenberg, 1982). In this paper, we label the former type of technical progress as *discrete innovation*, while the latter as *continuous improvement*. For example, in the petroleum refining industry, five major new processes (thermal cracking, thermal reforming, polymerization, catalytic cracking, and catalytic reforming) had been introduced between the 1910s and the 1950s. Enos (1958) pointed out that production efficiency of each process was improved after its initial introduction in a variety of ways such as better equipment design and the elimination of “bottlenecks”, and found that such improvement resulted in substantial cost reductions. Similarly, in his study of DuPont’s rayon plants, Hollander (1965) distinguished between major and minor technical change, where a minor technical change involved an “evolutionary” alternation in the existing techniques whereas a major change involved a significant departure from existing methods.

This paper investigates the interplay between discrete innovation and continuous improvement in the presence of competitive pressure, and studies how firms’ incentives to conduct continuous improvement are affected by changes in the degree of competition and the nature of discrete innovation.

We consider a Hotelling style duopoly model in which firms’ locations are fixed. Each firm makes decisions concerning its investments in discrete innovation, and continuous improvement on the existing technology. In general, discrete innovation involves significant uncertainty. According to Mansfield et al. (1971), a survey of 120 large companies doing a substantial amount of R&D indicated that, in half of these firms, at least 60% of the R&D projects never resulted in a commercially used product or process.<sup>1</sup> We capture the uncertainty by assuming that the investment in discrete innovation turns into a success with a certain probability. On the other hand, investment in continuous improvement involves no uncertainty in our model. Note that, in this class of models, competitive pressure is captured by transport cost. That is, a reduction in transport cost increases the substitutability between the two firm’s products, which in turn intensifies the competition between them.

Our model captures a key interplay between discrete innovation and continuous improve-

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<sup>1</sup>See also, for example, Schmookler (1966), Aghion and Howitt (1992), and Grossman and Helpman (1991).

ment by assuming that the improvement made upon the existing technology is not effective for the new technology introduced by a successful discrete innovation. That is, the very success of discrete innovation makes continuous improvement obsolete, and hence reduces the payoff of continuous improvement. Redding (2002) recently made a distinction between “fundamental innovations” and “secondary innovations” in his model of endogenous innovation and growth, where the secondary knowledge acquired for one fundamental technology has limited relevance for the next. This distinction is similar to our distinction between discrete innovation and continuous improvement. Redding’s analysis, however, focuses on path dependence and technological lock-in of technological progress, and does not incorporate competitive pressure which is a crucial element of our analysis. His analysis is therefore fundamentally different from ours (see Section 2 for details).

Does competitive pressure foster innovation? Our analysis offers a new perspective on this important question, which goes back at least to Schumpeter (1943) and Arrow (1962). Effects of competitive pressure on firms’ innovation incentives have been previously explored in the theoretical industrial organization literature, where innovative activity is often modelled as deterministic investment in cost reduction (which is continuous improvement in our terminology). Recently, Vives (2007) made an important contribution by investigating this question under general functional specifications of demand system. Vives found, among other things, that an increase in competitive pressure measured by product substitutability increases (although perhaps weakly) cost reduction expenditure per firm provided the average demand for varieties does not shrink, and this finding is consistent with the results obtained by previous studies under particular functional specifications (see Section 2 for details).

We contribute to the literature by demonstrating that the result can be overturned when the interplay between continuous improvement and discrete innovation is explicitly taken into account. In particular, our model predicts that an increase in competitive pressure measured by product substitutability *decreases* firms’ incentives to conduct continuous improvement in a broad range of parameterizations. To the best of our knowledge, no previous papers in the literature made an explicit distinction between discrete innovation and continuous improvement, which is the driving force of our result.

How do changes in the nature of discrete innovation affect firms’ incentives to conduct continuous improvement? The interplay between discrete innovation and continuous improvement yields a new prediction on this question. In particular, our model predicts that

an increase in the size of discrete innovation decreases firms' incentives to conduct continuous improvement in a broad range of parameterizations.

In Section 6, we explore the real-world relevance and usefulness of the model through field research. Continuous improvement had been regarded as an important source of strength in Japanese manufacturing until the 1980s. However, several studies have found that levels of continuous improvement have recently decreased in a number of Japanese manufacturing firms. To understand the causes of the declining focus on continuous improvement in Japan, we conducted detailed field research at two Japanese manufacturing firms. By applying the model to the findings from our field research, we demonstrate that the model offers fresh insights on possible mechanisms behind the changing nature of innovation that we observed at these firms.

The rest of the paper is organized as follows: Section 2 discusses the related literature. Section 3 presents a Hotelling style duopoly model that incorporates the interplay between discrete innovation and continuous improvement. Section 4 analyzes the model, presents comparative statics results concerning the equilibrium level of continuous improvement, and discusses how the model can be applied to innovative activities of intermediate-goods producers. Section 5 explores an extension of the model in which the success probability of discrete innovation is endogenized. Section 6 presents findings from our field research, and discuss how our model can be applied to shed light on what we observed. Section 7 offers concluding remarks.

## **2 Relationship to the literature**

The present paper contributes to the industrial organization literature that theoretically investigates relationships between competition or market structure and firms' innovation incentives. In models that analyze the extent of innovation, innovative activity is typically modeled as deterministic investment in cost reduction (see, for example, Dasgupta and Stiglitz, 1980; Spence, 1984; Tandon, 1984; Boone, 2000; Vives, 2006). Vives (2007) analyzed the effects of competition on cost-reducing R&D effort under general functional specifications and a variety of market structures, and found that increasing the number of firms tends to reduce R&D effort, whereas increasing the degree of product substitutability, with or without free entry, increases R&D effort provided the average demand for varieties does not shrink. These findings are consistent with the results obtained by previous studies

under particular functional specifications. On the other hand, in models that analyze the timing of innovation (i.e. “patent race” type models), R&D investment either stochastically or deterministically affects the eventual date at which an innovation is successfully introduced, where higher level of investment results in faster innovation. See Reinganum (1989) for a survey on the literature.

In the theoretical industrial organization literature mentioned above, to the best of our knowledge, no papers made a distinction between discrete innovation and continuous improvement and investigated the interplay between them. Boone (2000) analyzed the effects of competitive pressure on a firm’s incentives to invest in product and process innovations. In his model, each agent decides whether to enter the market with a new product and, if he/she enters, how much to invest to improve its production efficiency. That is, product innovation consists of entry of agents in this model, whereas we model discrete innovation by existing firms. Furthermore, our model captures the idea that continuous improvement is not effective for the new process or product introduced by a successful discrete innovation, which is not captured by Boone’s model. Also, the patent-design literature has addressed two-stage innovation, where a second innovation builds upon the first (see, for example, Green and Scotchmer, 1995; Chang, 1995). In these models, although the second innovation is an improvement upon the first, it is still discrete innovation rather than continuous improvement which consists of numerous minor improvements and modifications made upon the existing technology.

Similarly, relationship between competition or market structure and innovation have been investigated in the empirical industrial organization literature. Recent papers in this literature pointed to a positive correlation between product market competition and innovative activity (see e.g. Geroski, 1990; Nickell, 1996; Blundell, Griffith and Van Reenen, 1999). Geroski (1990) used data based on a study of 4378 major innovations in the UK, 1945-83, while in Blundell et al. (1999) innovation is a count of “technologically significant and commercially important” innovations commercialized by the firm. That is, these papers analyzed discrete innovation in our terminology. On the other hand, Nickell (1996) found that competition is associated with higher rates of total factor productivity growth. Again, to the best of our knowledge, no papers in this literature made a distinction between discrete innovation and continuous improvement as in the present paper.

Distinctions between different types of technological change have been explored in several endogenous growth models. For example, Jovanovic and Rob (1990) formalized the

distinction between extensive and intensive search, where extensive search seeks major breakthroughs while intensive search attempts to refine such breakthroughs. Also, Young (1993) developed a model that incorporates an interaction between invention and learning by doing, and Aghion and Howitt (1996) introduced the distinction between research and development into Schumpeterian growth model. Redding (2002) recently proposed a model of endogenous innovation and growth, in which technological progress is the result of a combination of “fundamental innovations” (which opens up whole new areas for technological development) and “secondary innovations” (which are the incremental improvements that realize the potential in each fundamental innovation). As in our model, Redding’s model incorporates the idea that the secondary knowledge acquired for one fundamental technology has often limited relevance for the next, and hence his distinction is perhaps closest to our distinction between discrete innovation and continuous improvement. However, none of these models incorporate competitive pressure, which is a crucial element of our analysis. Our model, therefore, is fundamentally different from models in this literature.

In summary, relationships between competitive pressure and firms’ innovation incentives have been investigated in the industrial organization literature, but the interplay between discrete innovation and continuous improvement have not been explored in this literature. On the other hand, distinctions between different types of technological change have been explored in endogenous growth models, but they did not incorporate competitive pressure. We combine the two literatures and provide fresh insight on the interplay between competitive pressure and firms’ incentives to invest in two types of innovation activities, discrete innovation and continuous improvement.

### 3 Model

Assume that a unit mass of consumers are uniformly distributed on the line segment  $[0, 1]$ . Each consumer is indexed by her location  $y \in [0, 1]$  on the line, which represents her ideal point in the product characteristic space. Each consumer buys at most one unit of exactly one of the two varieties sold in the market. The price and location of variety  $i$  ( $= A, B$ ) on the line are denoted by  $p_i$  and  $z_i$  respectively where  $z_i \in [0, 1]$  for all  $i$  ( $= A, B$ ). The indirect utility for consumer  $y \in [0, 1]$  of purchasing one unit of variety  $i$  is given by  $V_i(y) = R - p_i - t|z_i - y|$ , where  $R$  is the gross utility from consuming one unit of any variety,  $|z_i - y|$  denotes the distance between  $z_i$  and  $y$ , and  $t > 0$  denotes per unit transport cost.

The utility from not purchasing any variety is normalized to zero.

There are two firms, denoted  $A$  and  $B$ , located respectively at 0 and 1. Firm  $i$  ( $= A, B$ ) sells variety  $i$  at price  $p_i$ , and hence  $z_A = 0$  and  $z_B = 1$ . Each firm  $i$  has a constant marginal cost  $c_i$  and no fixed costs of production. Each firm can invest in **discrete innovation** ( $DI$ ) and **continuous improvement** ( $CI$ ) to reduce its cost. If firm  $i$  makes no investments in  $DI$  and  $CI$ , then  $c_i = c$  ( $> 0$ ). By investing a fixed amount  $F$  ( $> 0$ ) in  $DI$ , each firm  $i$  can reduce its constant marginal cost from  $c$  to  $c - \Delta$  ( $\Delta \in (0, c)$ ) with probability  $s \in (0, 1)$ . Here we interpret  $\Delta$  to be the size of cost reduction due to the new technology introduced by the success in the discrete innovation. As pointed out in Introduction, in general discrete innovation involves significant uncertainty, which is incorporated in our model by the success probability  $s$ . Assume that the two firms' successes in  $DI$  are mutually independent. This assumption is for simplifying the algebra, and not crucial for our results. Note that Section 5 explores an extension of the model in which the success probability of  $DI$  is endogenously determined.

Regarding  $CI$ , each firm  $i$  can reduce its constant marginal cost from  $c$  to  $c - x_i$  by investing  $d(x_i)$  in  $CI$ , where  $d(\cdot)$  is a convex function and  $x_i \in [0, X]$  ( $X \in (0, \Delta)$ ). To obtain closed form solutions in the analysis, let  $d(x) = \frac{\gamma x^2}{2}$  ( $\gamma > 0$ ). The return from investment in  $CI$  is certain, and we interpret  $x_i$  to be the size of cost reduction due to the continuous improvement made by firm  $i$  upon the existing technology. If firm  $i$ 's investment in  $DI$  turns out to be successful, then firm  $i$  chooses the new technology ( $c_i = c - \Delta$ ) or the old technology with improvement ( $c_i = c - x_i$ ) where we assume that  $CI$  is not effective for the new technology introduced by the successful  $DI$ . The firm chooses the new technology under our assumption of  $X \in (0, \Delta)$ . That is, we assume that the successful  $DI$  is more cost effective than the highest possible level of  $CI$  made upon the existing technology.

In our model, we incorporate both  $DI$  and  $CI$  as investments in cost reduction (process innovation). Our results, however, are unchanged under alternative model setups in which  $DI$  and/or  $CI$  are investments in quality enhancement (product innovation), affecting the product's gross utility  $R$  instead of the constant marginal cost  $c$ . For instance, we can interpret  $DI$  to be an investment in the development of a new product. Suppose that, if firm  $i$ 's investment in  $DI$  turns out to be successful, then firm  $i$  chooses the new product ( $R_i = R + \Delta$  and  $c_i = c$ ) or the existing product with a reduced cost due to  $CI$  ( $R_i = R$  and  $c_i = c - x_i$ ), where  $R_i$  denotes the gross utility of firm  $i$ 's product. The results under this alternative setup are the same as the ones under the setup described above. The results are

also unchanged under two other possible combinations: (i) A success in  $DI$  increases  $R_i$  by  $\Delta$  while  $CI$  increases  $R_i$  by  $x_i$ , or (ii) A success in  $DI$  reduces  $c_i$  by  $\Delta$  while  $CI$  increases  $R_i$  by  $x_i$ . In other words, the distinction between product innovation (quality enhancement) and process innovation (cost reduction) is not the focus of our analysis. The focus is the idea that the investment in  $CI$ , be it cost reduction or quality enhancement, is nullified if the new process or product is introduced upon a success in  $DI$ .

Following previous analyses in the industrial organization literature (see, for example, Raith, 2003; Aghion and Schankerman, 2004; Vives, 2006; Baggs and de Bettignes, 2007), we interpret that the per unit transport cost,  $t$ , captures the degree of competitive pressure between firms. That is, a reduction in  $t$  increases the substitutability between the products of firms A and B, which in turn intensifies the competition between them.

We consider the two-stage game described below:

**Stage 1 [Investment]:** Each firm  $i$  simultaneously and non-cooperatively decides whether or not to invest in  $DI$ , and chooses  $x_i \in [0, X]$ , the level of investment in  $CI$ .

**Stage 2 [Bertrand competition]:** The outcomes of  $DI$  are realized and become common knowledge. Each firm  $i$ 's constant marginal cost of production is  $c_i = c - \Delta$  if its investment in  $DI$  turns out to be successful, and  $c_i = c - x_i$  otherwise. Given  $(c_A, c_B)$ , each firm  $i$  simultaneously and non-cooperatively chooses  $p_i$  to maximize its profit.

## 4 Analysis

In this section we first analyze the model when  $F$ , the fixed cost for  $DI$ , is sufficiently small so that both firms invest in  $DI$  in the symmetric pure-strategy equilibrium. We will then discuss robustness of the results when  $F$  takes a greater value, and how the model can be applied to innovative activities of intermediate-goods producers.

### 4.1 Symmetric pure-strategy equilibrium

We derive Subgame Perfect Nash Equilibria (SPNE) of the model described above, focusing on symmetric equilibria. In this subsection we will focus our analysis on the case in which  $F$  (the fixed cost for  $DI$ ) is sufficiently small so that both firms  $A$  and  $B$  invest in  $DI$  in pure-strategy equilibria. In the next subsection we will discuss the robustness of our results when  $F$  takes larger values. Given that competitive pressure is a critical element in our analysis,



we assume that the gross utility from consuming a variety (captured by  $R$ ) is high enough so that the two firms compete over all consumers in the equilibrium.<sup>2</sup> We also assume that  $\gamma$  (the cost parameter for investment in  $CI$ ) is large enough to ensure an interior solution for the equilibrium level of investment in  $CI$ .<sup>3</sup>

First consider stage 2 subgames. At stage 2, given a cost vector  $(c_A, c_B)$ , each firm  $i$  simultaneously and non-cooperatively chooses  $p_i$  to maximize its profit. Let  $(p_A, p_B)$  be given, and suppose that  $R$  is sufficiently large so that all consumers purchase one unit of a variety. Then, consumer  $y \in [0, 1]$  purchases variety  $A$  from firm  $A$  if  $p_A + ty \leq p_B + t(1 - y) \Leftrightarrow y \leq \frac{1}{2} + \frac{p_B - p_A}{2t}$ . We then find that demand for variety  $i$ , denoted  $q_i(p_i, p_j)$ , is given by  $q_i(p_i, p_j) = \max\{0, \frac{1}{2} + \frac{p_j - p_i}{2t}\}$  if  $\frac{1}{2} + \frac{p_j - p_i}{2t} \leq 1$ , and 1 otherwise, where  $i, j = A, B$ ,  $i \neq j$ . Each firm  $i$  chooses  $p_i$  to maximize  $(p_i - c_i)q_i(p_i, p_j)$ , where  $c_i = c - \Delta$  if firm  $i$  succeeds in  $DI$  and  $c_i = c - x_i$  otherwise. If  $|c_A - c_B| \leq 3t$ , the SPNE outcome of the stage 2 subgame is characterized as follows:

$$\tilde{p}_i(c_i, c_j) \equiv t + \frac{2c_i + c_j}{3}, \tilde{q}_i(c_i, c_j) \equiv \frac{1}{2} + \frac{c_j - c_i}{6t}, \quad (1)$$

$$\tilde{\pi}_i(c_i, c_j) \equiv (\tilde{p}_i(c_i, c_j) - c_i)\tilde{q}_i(c_i, c_j) = 2t\tilde{q}_i(c_i, c_j)^2, \quad (2)$$

where  $i, j = A, B$ ,  $i \neq j$ , and  $\tilde{p}_i(c_i, c_j)$ ,  $\tilde{q}_i(c_i, c_j)$  and  $\tilde{\pi}_i(c_i, c_j)$  denote firm  $i$ 's equilibrium price, quantity and profit, respectively. Else, if  $|c_A - c_B| > 3t$  then

$$\tilde{p}_i(c_i, c_j) = I(c_j - t) + (1 - I)c_i, \quad \tilde{q}_i(c_i, c_j) = I, \quad (3)$$

$$\tilde{\pi}_i(c_i, c_j) = I(c_j - c_i - t), \quad (4)$$

where the indicator variable  $I = 1(0)$  if and only if  $c_i < (>)c_j$ . As mentioned earlier, we assume for now that  $F$  is sufficiently small so that both firms invest in  $DI$  at stage 1. In the subsequent stage 2 subgame, each firm  $i$  chooses  $x_i$  to maximize its expected overall profit, which is given by

$$s\pi_i^S(x_i, x_j) + (1 - s)\pi_i^F(x_i, x_j) - \frac{\gamma x_i^2}{2} - F, \quad (5)$$

where  $i, j = A, B$  ( $i \neq j$ ),  $\pi_i^S(x_i, x_j)$  denotes each firm  $i$ 's expected stage 2 profit conditional upon its success in  $DI$ , and  $\pi_i^F(x_i, x_j)$  is analogously defined conditional upon its failure in

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<sup>2</sup>More precisely, we assume that the value of  $R$  is high enough so that the following property holds: Every consumer who purchases a product from firm  $i$  ( $= A, B$ ) in the equilibrium could enjoy a positive indirect utility by purchasing a product from firm  $j$  ( $\neq i$ ), instead, at its equilibrium price.

<sup>3</sup>In particular, we assume that  $\gamma > \max\{\frac{1}{9t}, \frac{1}{3X}\}$ .

*DI*. Recall that  $c_i = c - \Delta$  upon firm  $i$ 's success in *DI*, while  $c_i = c - x_i$  upon its failure. Hence we have

$$\pi_i^S(x_i, x_j) = s\tilde{\pi}_i(c - \Delta, c - \Delta) + (1 - s)\tilde{\pi}_i(c - \Delta, c - x_j), \quad (6)$$

$$\pi_i^F(x_i, x_j) = s\tilde{\pi}_i(c - x_i, c - \Delta) + (1 - s)\tilde{\pi}_i(c - x_i, c - x_j). \quad (7)$$

Given this, we find that the symmetric pure-strategy equilibrium of the entire game is unique, and in the equilibrium each firm  $i$  chooses  $x_i = x^*$ , where

$$x^* \equiv \max\left\{\frac{(1-s)(3t-s\Delta)}{9t\gamma-s(1-s)}, \frac{(1-s)^2}{3\gamma}\right\}. \quad (8)$$

We are now ready to present comparative statics results concerning  $x^*$ , the equilibrium level of *CI*.

We first explore the effect of competitive pressure on  $x^*$ . Effects of competitive pressure on firms' innovation incentives have been previously explored in the theoretical industrial organization literature, where innovative activity is typically modelled as deterministic investment in cost reduction (which is *CI* in our model). As mentioned earlier, a robust finding is that an increase in competitive pressure measured by product substitutability increases (although perhaps weakly) R&D effort per firm, provided the average demand for varieties does not shrink as the degree of product substitutability decreases.

We contribute to the literature by demonstrating that the result can be overturned when the interplay between *CI* and *DI* is explicitly taken into account in the presence of competitive pressure.

**Proposition 1:** The equilibrium level of continuous improvement,  $x^*$ , decreases as the degree of competitive pressure increases. More precisely, there exists a threshold value  $\bar{\Delta} \equiv 3t + \frac{(1-s)^2}{3\gamma} > 0$  such that  $\frac{dx^*}{dt} > 0$  if  $\Delta < \bar{\Delta}$  while  $\frac{dx^*}{dt} = 0$  if  $\Delta > \bar{\Delta}$ .

Recall that in our model, competitive pressure is captured by per unit transport cost  $t$ : As  $t$  decreases, product substitutability increases, which in turn increases competitive pressure. Hence,  $\frac{dx^*}{dt} > 0$  means that the equilibrium level of *CI* decreases as competitive pressure increases.

To understand the main intuition, consider firm  $i$ 's expected return from choosing the level of *CI* at  $x_i = x$ , holding firm  $j$ 's ( $\neq i$ ) level of *CI* fixed at  $x_j = x$ . Suppose that firm  $i$  fails in *DI* while firm  $j$  succeeds in it, so that  $c_i = c - x > c_j = c - \Delta$ . Because of the

cost disadvantage, firm  $i$ 's equilibrium quantity  $\tilde{q}_i(c - x, c - \Delta)$  is less than  $\frac{1}{2}$ . As product substitutability increases (i.e., as  $t$  decreases), the cost difference becomes more important determinant of firms' competitive advantage. In other words, more competition magnifies the impact of cost differences,<sup>4</sup> and hence firm  $i$ 's equilibrium quantity  $\tilde{q}_i(c - x, c - \Delta)$  decreases as competition intensifies. In contrast, if both firms fail in  $DI$ , there are no cost differences between them and hence firm  $i$ 's quantity  $\tilde{q}_i(c - x, c - x) = \frac{1}{2}$  remains unchanged as competition intensifies. Then, conditional upon firm  $i$ 's failure in  $DI$ , firm  $i$ 's expected quantity decreases as competition intensifies because firm  $j$  succeeds in  $DI$  with a positive probability  $s$ . This works in the direction of reducing firm  $i$ 's expected return from  $CI$ , because firm  $i$  can apply unit-cost reduction through  $CI$  to smaller expected amount of its production as competition intensifies. We call it the *share-reduction effect* of competition. This is a new effect arising from the interplay between  $CI$  and  $DI$ , and an important driving force of the result that increasing competitive pressure reduces the equilibrium level of continuous improvement.

In what follows, we explain the mechanism behind Proposition 1 in more details for the case of  $\Delta < \bar{\Delta}$ , and compare our result with the previous findings in the literature. Recall that firm  $i$ 's investment in  $CI$  turns out to be useful when it fails in  $DI$ , and, contingent upon firm  $i$ 's failure in  $DI$ , firm  $j$  succeeds in  $DI$  with probability  $s$ . Hence firm  $i$  chooses  $x_i$  to maximize  $(1 - s)\pi_i^F(x_i, x_j) - d(x_i)$ , where we have (see equation (7))

$$(1 - s)\pi_i^F(x_i, x_j) = (1 - s)s\tilde{\pi}_i(c - x_i, c - \Delta) + (1 - s)^2\tilde{\pi}_i(c - x_i, c - x_j). \quad (9)$$

In the equilibrium we have  $\frac{\partial}{\partial x_i}(1 - s)\pi_i^F(x^*, x^*) - d'(x^*) = 0$ . How does an increase in competitive pressure (i.e., a decrease in  $t$ ) affect  $\frac{\partial}{\partial x_i}(1 - s)\pi_i^F(x^*, x^*)$ , firm  $i$ 's marginal return from  $CI$ ? To answer this question, we need to find the sign of

$$\frac{\partial^2}{\partial t \partial x_i}(1 - s)\pi_i^F(x^*, x^*) = s(1 - s)\frac{\partial^2}{\partial t \partial x_i}\tilde{\pi}_i(c - x^*, c - \Delta) + (1 - s)^2\frac{\partial^2}{\partial t \partial x_i}\tilde{\pi}_i(c - x^*, c - x^*). \quad (10)$$

First consider  $\frac{\partial^2}{\partial t \partial x_i}\tilde{\pi}_i(c - x^*, c - \Delta)$ , which appears in the first term of the RHS of equation (10) and corresponds to the case in which firm  $i$  fails but firm  $j$  succeeds in  $DI$ . We have

$$\tilde{\pi}_i(c - x^*, c - \Delta) = (p_{iFS}(x^*, t) - c_{iF}(x^*))q_{iFS}(x^*, t), \quad (11)$$

where  $p_{iFS}(x_i, t)$  and  $q_{iFS}(x_i, t)$  denote firm  $i$ 's equilibrium price and quantity, respectively, when firm  $i$  fails but firm  $j$  succeeds in  $DI$ , and  $c_{iF}(x_i) \equiv c - x_i$  denotes firm  $i$ 's constant

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<sup>4</sup>We would like to thank Michael Raith for pointing this intuition to us.

marginal cost when it fails in  $DI$ . We then have

$$\frac{\partial}{\partial x_i} \tilde{\pi}_i(c-x^*, c-\Delta) = \underbrace{q_{iFS}(x^*, t) \frac{\partial}{\partial x_i} (p_{iFS}(x^*, t) - c_{iF}(x^*))}_{\text{Share-reduction effect}} + (p_{iFS}(x^*, t) - c_{iF}(x^*)) \frac{\partial}{\partial x_i} q_{iFS}(x^*, t). \quad (12)$$

Equation (12) captures three effects of competition, *share-reduction effect*, *business-stealing effect*, and *rent-reduction effect*, and these effects together result in  $\frac{\partial^2}{\partial t \partial x_i} \tilde{\pi}_i(c-x^*, c-\Delta) > 0$ .

(i) *Share-reduction effect*: This is the new effect captured by our analysis as mentioned above, represented by the first term of the RHS of (12). We have  $\frac{\partial}{\partial x_i} (p_{iFS}(x^*, t) - c_{iF}(x^*)) = \frac{1}{3}$ . That is, firm  $i$ 's incremental investment in  $CI$  increases its price-cost margin, and the incremental price-cost margin  $\frac{\partial}{\partial x_i} (p_{iFS}(x^*, t) - c_{iF}(x^*))$  is independent of  $t$ . At the same time, firm  $i$ 's equilibrium quantity  $q_{iFS}(x^*, t) = \frac{1}{2} - \frac{\Delta-x^*}{6t}$  decreases as  $t$  decreases, because more competition magnifies the impact of firm  $i$ 's cost disadvantage represented by  $\Delta - x^*$ . The result is that, as competitive pressure increases, the first term  $q_{iFS}(x^*, t) \frac{\partial}{\partial x_i} (p_{iFS}(x^*, t) - c_{iF}(x^*))$  decreases, working in the direction of reducing firm  $i$ 's marginal return from  $CI$ .

(ii) *Business-stealing effect* and *rent-reduction effect*: These two effects have been explored by several recent studies in the literature (Raith, 2003; de Bettignies, 2006; Baggs and de Bettignies, 2007), and are captured by the second term of the RHS of (12).<sup>5</sup> Firm  $i$ 's incremental investment in  $CI$  reduces its cost disadvantage against firm  $j$ . This increases firm  $i$ 's equilibrium quantity by  $\frac{\partial}{\partial x_i} q_{iFS}(x^*, t) = \frac{1}{6t} > 0$ , which in turn increases its profit by  $(p_{iFS}(x^*, t) - c_{iF}(x^*)) \frac{\partial}{\partial x_i} q_{iFS}(x^*, t)$ . Differentiating this term with respect to  $t$  yields

$$\underbrace{(p_{iFS}(x^*, t) - c_{iF}(x^*)) \frac{\partial^2}{\partial t \partial x_i} q_{iFS}(x^*, t)}_{\text{Business-stealing effect}} + \underbrace{\frac{\partial}{\partial t} (p_{iFS}(x^*, t) - c_{iF}(x^*)) \frac{\partial}{\partial x_i} q_{iFS}(x^*, t)}_{\text{Rent-reduction effect}}. \quad (13)$$

Concerning the first term, we have  $\frac{\partial^2}{\partial t \partial x_i} q_{iFS}(x^*, t) = -\frac{1}{6t^2} < 0$ . As  $t$  decreases, consumers become more price sensitive. This implies that, by reducing its cost by  $CI$ , firm  $i$  can more easily increase its equilibrium quantity. Hence, as competition intensifies, the business-stealing effect works in the direction of increasing firm  $i$ 's incentive to invest in  $CI$ ; that is,  $(p_{iFS}(x^*, t) - c_{iF}(x^*)) \frac{\partial^2}{\partial t \partial x_i} q_{iFS}(x^*, t) = (t - \frac{\Delta-x^*}{3}) (-\frac{1}{6t^2}) < 0$  holds, given  $\Delta < \bar{\Delta} \Rightarrow t > \frac{\Delta-x^*}{3}$ .

<sup>5</sup>Rent-reduction effect is the terminology used by de Bettignies (2006) and Baggs and de Bettignies (2007). Raith (2003) labelled this effect as a *scale effect*

At the same time, as competition intensifies, the price-cost margin becomes smaller; that is,  $\frac{\partial}{\partial t}(p_{iFS}(x^*, t) - c_{iF}(x^*)) = 1 > 0$ , implying  $\frac{\partial}{\partial t}(p_{iFS}(x^*, t) - c_{iF}(x^*))\frac{\partial}{\partial x_i}q_{iFS}(x^*, t) = 1(\frac{1}{6t}) > 0$ . This is the rent-reduction effect. We have that  $(t - \frac{\Delta - x^*}{3})(-\frac{1}{6t^2}) + \frac{1}{6t} = \frac{\Delta - x^*}{18t^2} > 0$ ; that is, the business-stealing effect is dominated by the rent-reduction effect.

In sum, concerning the case in which firm  $i$  fails but firm  $j$  succeeds in  $DI$ , the share-reduction effect works in the direction of reducing firm  $i$ 's marginal return from  $CI$  as competition intensifies. Although the business-stealing effect works in the opposite direction, this effect is dominated by the rent-reduction effect. Hence, the three effects together result in  $\frac{\partial^2}{\partial t \partial x_i} \tilde{\pi}_i(c - x^*, c - \Delta) > 0$ .

Next consider  $\frac{\partial^2}{\partial t \partial x_i} \tilde{\pi}_i(c - x^*, c - x^*)$ , which appears in the second term of the RHS of equation (10) and corresponds to the case in which both firms  $i$  and  $j$  fail in  $DI$ . The share-reduction effect is absent in this case, because each firm's equilibrium quantity is  $\frac{1}{2}$  regardless of the level of  $t$ . Also, the business-stealing effect and the rent-reduction effect exactly cancels out each other in this case, consistent with previous findings in the literature (see Raith, 2003; Baggs and de Bettignies, 2007). Hence we find  $\frac{\partial^2}{\partial t \partial x_i} \tilde{\pi}_i(c - x^*, c - x^*) = 0$ .

Therefore we find  $\frac{\partial^2}{\partial t \partial x_i} \tilde{\pi}_i(c - x^*, c - \Delta) > \frac{\partial^2}{\partial t \partial x_i} \tilde{\pi}_i(c - x^*, c - x^*) = 0$ , implying  $\frac{\partial^2}{\partial t \partial x_i} (1 - s)\pi_i^F(x^*, x^*) > 0$ . That is, as competitive pressure increases, firm  $i$ 's marginal return from  $CI$  decreases and hence the equilibrium level of  $CI$  also decreases. This results in  $\frac{dx^*}{dt} > 0$  if  $\Delta < \bar{\Delta}$ , as stated in Proposition 1.

We now compare our result to the previous findings in the literature. Consider a standard set-up in which  $n$  ex ante symmetric firms can produce differentiated products where the degree of product substitutability is represented by parameter  $t > 0$ . Each firm  $i$  ( $= 1, 2, \dots, n$ ) chooses a level of its per-unit cost reduction  $x_i$  (which is  $CI$  in our terminology) by incurring a convex cost  $d(x_i)$ , and then compete against each other in the product market by producing variety  $i$  of the product. As mentioned above, a robust finding in this class of models is  $\frac{dx^*}{dt} \leq 0$  where each firm  $i$  chooses  $x_i = x^*$  in the equilibrium, provided that the average demand for varieties does not shrink as  $t$  decreases. That is, an increase in competitive pressure (i.e. a decrease in  $t$ ) increases (although perhaps weakly) the level of  $CI$ . The share-reduction effect is zero in this set-up because each firm's equilibrium market share is  $1/n$  regardless of the level of  $t$ . Concerning the business-stealing effect and the rent-reduction effect, the former (at least weakly) dominates the latter in this class of models, resulting in  $\frac{dx^*}{dt} \leq 0$ .

We have demonstrated that the result can be overturned in the presence of  $DI$ . First, by

exploring the interplay between  $CI$  and  $DI$ , we have discovered the share-reduction effect of competition, which works in the direction of reducing marginal return from  $CI$  as competition intensifies. Second, although the business-stealing effect and the rent-reduction effect exactly cancel out under location models in the absence of  $DI$ , the former is dominated by the latter in the presence of  $DI$ . An effect similar to the second effect was identified in a different context by de Bettignies (2006), who studied the effects of product market competition on firm boundaries. In his Hotelling-style duopoly model in which a manufacturer-retailer pair is located at 0 and 1 of the line segment  $[0, 1]$ , each manufacturer increases its product quality by choosing not to integrate with the paired retailer. De Bettignies found that, given one manufacturer chooses disintegration, the other manufacturer's benefit from choosing disintegration decreases as competition intensifies, because business-stealing effect is dominated by rent-reduction effect. To the best of our knowledge, however, the present paper is the first one to find that the business-stealing effect can be dominated by the rent-reduction effect in the context of competitive pressure and innovation incentives.<sup>6</sup>

We now turn to the next question: How do changes in the nature of  $DI$  affect firms' incentives to invest in  $CI$ ? By making a distinction between  $CI$  and  $DI$  and capturing their connection in the presence of competition, our model provides novel answers to this question.

**Proposition 2:** The equilibrium level of continuous improvement,  $x^*$ , declines as the size of discrete innovation increases. More precisely,  $\frac{dx^*}{d\Delta} < 0$  if  $\Delta < \bar{\Delta}$  while  $\frac{dx^*}{d\Delta} = 0$  if  $\Delta > \bar{\Delta}$ , where  $\bar{\Delta}$  is as defined in Proposition 1.

Competition plays a crucial role in driving this result. To see this, first consider what happens without competition by supposing that firm  $i$  is a monopolist, investing in  $DI$  and  $CI$ . Then, since firm  $i$ 's investment in  $CI$  is useful only when its  $DI$  turns out to be unsuccessful, the size of  $DI$  does not affect firm  $i$ 's incentive to invest in  $CI$ .

The presence of competition significantly changes the scenario. As mentioned earlier, firm  $i$ 's expected marginal benefit from its investment in  $CI$  is  $\frac{\partial}{\partial x_i}(1-s)\pi_i^F(x^*, x^*)$  in the

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<sup>6</sup>The share-reduction effect was not captured by de Bettignies' model because of its discrete nature. That is, given one manufacturer chooses disintegration, the other manufacturer can make its market share to be  $\frac{1}{2}$  by choosing disintegration over integration, regardless of the degree of competitive pressure. This results in the absence of the share-reduction effect in this model.

equilibrium. We have

$$\frac{\partial^2}{\partial \Delta \partial x_i} (1-s)\pi_i^F(x^*, x^*) = s(1-s) \frac{\partial^2}{\partial \Delta \partial x_i} \tilde{\pi}_i(c-x^*, c-\Delta). \quad (14)$$

That is, a change in the size of  $DI$  affects firm  $i$ 's marginal benefit of investment in  $CI$  when firm  $i$  fails and firm  $j$  succeeds in  $DI$ . In this case, firm  $j$  has a cost advantage because of its success in  $DI$ . The advantage increases as  $\Delta$  increases, which reduces firm  $i$ 's market share. The smaller market share in turn reduces firm  $i$ 's marginal benefit of investment in  $CI$ . This implies that the equilibrium level of  $CI$  is decreasing in the size of  $DI$ . In the presence of competition, it is the possibility of firm  $i$ 's rival's success in  $DI$  that reduces firm  $i$ 's incentive to invest in  $CI$ .

Finally, in Proposition 3 we consider the effect of a change in the success probability of  $DI$  (denoted  $s$ ).

**Proposition 3:** The equilibrium level of continuous improvement,  $x^*$ , declines as the success probability of discrete innovation increases. That is,  $\frac{dx^*}{ds} < 0$ .

Logic behind the result is simple, and it does not rely on competitive pressure. Given each firm  $i$ 's investment in  $CI$  is useful only when it fails in its  $DI$ , its marginal benefit of investing in  $CI$  decreases as the success probability of  $DI$  increases. This implies the result.

## 4.2 Robustness of the results<sup>7</sup>

Thus far we have focused on the case in which  $F$  is sufficiently small so that both firms  $A$  and  $B$  invest in  $DI$  in pure-strategy equilibria. In this subsection, we discuss the robustness of the results when this assumption is relaxed. In order to focus our analysis on symmetric equilibria, we allow mixed strategies for firms' investments in  $DI$ . We find that there exist symmetric equilibria in mixed strategies characterized by  $(\sigma^*, x^*)$ , where  $\sigma^*$  ( $\in [0, 1]$ ) denotes the probability for each firm to invest in  $DI$  in the equilibrium, and  $x^*$  ( $\geq 0$ ) denotes the level of each firm's investment in  $CI$  in the equilibrium. We find that there exist a value  $F'$  ( $> 0$ ) such that, if  $F \leq F'$ , then  $\sigma^* = 1$  holds in the equilibrium; that is, both firms invest in  $DI$  with probability 1 in the equilibrium. This equilibrium is identical to the pure-strategy equilibrium derived in the previous subsection. Also, we find that there exists a value  $F''$  ( $> F'$ ) such that  $0 < \sigma^* < 1$  if  $F' < F < F''$  while  $\sigma^* = 0$  if  $F \geq F''$ .

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<sup>7</sup>Details of the analyses for the results presented in this subsection are available upon request.

Suppose  $F' < F < F''$ . Then there exist symmetric equilibria characterized by  $(\sigma^*, x^*)$  that solves the following simultaneous equations:

$$\sigma^* = \frac{6st(\Delta - x^*) + s(\Delta - x^*)^2 - 18Ft}{2s^2(\Delta - x^*)^2}, \quad (15)$$

$$x^* = \frac{3t(1 - \sigma^*s) - \sigma^*s(1 - \sigma^*s)}{9kt - \sigma^*s(1 - \sigma^*s)}. \quad (16)$$

We have proved that there exists at least one solution to this system, but have not been able to rule out the possibility of multiple solutions. If more than one solution exist, then each solution pair  $(\sigma^*, x^*)$  corresponds to an equilibrium.

In what follows we discuss the robustness of the comparative statics results presented above in Propositions 1 - 3. Proposition 1 told us that, if  $F \leq F'$ , the equilibrium level of continuous improvement,  $x^*$ , declines as the degree of competitive pressure increases. If  $F' < F < F''$ , we have found that this result continues to hold as long as  $\frac{d\sigma^*}{dt} < 0$ . Holding  $\sigma^*$  fixed,  $x^*$  declines as the degree of competitive pressure increases (i.e. as  $t$  decreases) through the logic analogous to the one presented after Proposition 1. This effect is reinforced by the impact of  $t$  on  $\sigma^*$ , if  $\frac{d\sigma^*}{dt} < 0$ . That is, if  $\frac{d\sigma^*}{dt} < 0$ , then the equilibrium probability of success in  $DI$  increases as  $t$  decreases, which further reduces each firm's incentive to invest in  $CI$ . We have found that  $\frac{d\sigma^*}{dt} < 0$  holds for all  $s < \frac{1}{2}$ . However, if  $s \geq \frac{1}{2}$ , we were not able to rule out the possibility of  $\frac{d\sigma^*}{dt} > 0$ , and in such a case the result might be opposite to Proposition 1 under certain parameterizations.

Proposition 2 told us that, if  $F \leq F'$ ,  $x^*$  declines as the size of discrete innovation (captured by  $\Delta$ ) increases. If  $F' < F < F''$ , we have found that this result continues to hold as long as  $\frac{d\sigma^*}{d\Delta} > 0$ , which says that as the size of  $DI$  increases, each firm increases its probability to invest in  $DI$  in the mixed-strategy equilibrium. This makes an intuitive sense, and we found that  $\frac{d\sigma^*}{d\Delta} > 0$  holds under a range of parameterizations. We were however unable to rule out the possibility of  $\frac{d\sigma^*}{d\Delta} < 0$ , and in such a case the result might be opposite to Proposition 2. The result presented in Proposition 3 is robust when  $F' < F < F''$ . Holding  $\sigma^*$  fixed,  $x^*$  declines as the success probability in  $DI$  (captured by  $s$ ) increases. This is reinforced by  $\frac{d\sigma^*}{ds} > 0$ . That is, as  $s$  increases, firms invest in  $DI$  with higher probability, which further reduces firms' incentives to invest in  $CI$ .



### 4.3 Innovative activities of intermediate-goods producers

Thus far we have focused on innovative activities of final-goods producers. In reality, however, innovative activities undertaken by intermediate-goods producers (including two manufacturing firms in which we have conducted our field research) are equally important. In this subsection, we show that a mathematically equivalent model can be developed by considering a variant of our model in which two intermediate-goods producers, suppliers  $A$  and  $B$ , make investment decisions on the levels of their discrete innovation and continuous improvement under competitive pressure.

Consider two suppliers, denoted  $A$  and  $B$ , of intermediate goods, where supplier  $i$  ( $=A$  or  $B$ ) produces variety  $i$  of the intermediate goods. Suppliers  $A$  and  $B$  are located respectively at 0 and 1 of the line segment  $[0, 1]$ , where the location on the line segment represents the product characteristics of the intermediate goods. On the demand side, a unit mass of final-goods producers are uniformly distributed on the line segment  $[0, 1]$ , where each producer can be interpreted as an independent firm or a manufacturing plant of a firm that has a number of plants. Each final-goods producer procures one unit of the intermediate goods from supplier  $A$  or  $B$  to produce one unit of the final goods, and sells the final-goods to a unit mass of consumers at a price of  $R > 0$  (a given constant).

Each producer  $y$  ( $\in [0, 1]$ ) has its ideal characteristics of the intermediate product represented by  $y$ , which differ across producers ranging between 0 and 1. This specification captures the idea that they produce different varieties of the final-goods, and hence their ideal characteristics of the intermediate-goods are also different. If producer  $y$  procures the intermediate goods from supplier  $i$  ( $i = A$  or  $B$ ), its constant marginal cost for production is  $p_i + t|z_i - y| + \eta$  where  $p_i$  denotes the price of the intermediate goods  $i$ ,  $z_A = 0$  and  $z_B = 1$ , and  $\eta \geq 0$ . This cost specification captures, in a reduced form, the idea that producer  $y$ 's cost decreases as the product characteristics of the intermediate goods it procures gets closer to its ideal characteristics. Note that the production cost other than costs associated with the intermediate goods  $i$  is represented by  $\eta$ , which we normalize at zero.

Other details of this variant of the model are analogous to those of the base model. Each supplier  $i$  has a constant marginal cost  $c_i$  and no fixed costs of production, and can invest in discrete innovation ( $DI$ ) and continuous improvement ( $CI$ ) to reduce its cost. The nature and the costs of  $DI$  and  $CI$  are the same as in the base model. Timing of the game is also the same as in the base model.

This variant of the model has the same mathematical structure as that of the base model, and hence yields the same analytical results including three propositions presented above. In Section 6, we will discuss applications of the model to the findings from our field research in which we studied two intermediate-goods producers, AUTOPARTS and METAL.

## 5 Endogenizing the success probability of $DI$

So far, we have treated the success probability of  $DI$ ,  $s$ , as a parameter of the model. Here, we endogenize the success probability of  $DI$  and discuss the robustness of our findings. Suppose each firm  $i$  ( $= A, B$ ) can increase the success probability by increasing its investment in  $DI$ . In particular, suppose that each firm  $i$ 's success probability, denoted  $s_i \in [0, \theta)$  (where  $\theta \in (0, 1)$  is a given parameter), is determined by  $F(s_i)$ , where the investment cost function  $F(\cdot)$  is a twice continuously differentiable function with the following properties: (i)  $F(0) = 0$ , (ii)  $F'(s) > 0$  and  $F''(s) > 0$  for all  $s \in (0, \theta)$ , and (iii)  $\lim_{s \rightarrow 0} F'(s) = 0$  and  $\lim_{s \rightarrow \theta} F'(s) = \infty$ . An example of  $F(\cdot)$  satisfying these conditions is  $F(s) = ks/(\theta - s)$  for  $s \in (0, \theta)$ , where  $k > 0$  is a given constant. For the remainder of this section we assume that  $\Delta < 3t$ , which ensures that each firm invests a strictly positive amount in continuous improvement. The timing of the game is as follows. At stage 1, each firm  $i = (A, B)$  chooses  $x_i \in [0, X]$  and  $s_i \in [0, \theta)$ , and incurs investment costs  $d(x_i)$  and  $F(s_i)$  respectively, where the cost function of continuous improvement  $d(\cdot)$  has the same property as in the original model and  $F(s_i)$  is as described above. Stage 2 is the same as in the original model.

Corresponding to  $(s_i, s_j, x_i, x_j)$ , let

$$\Pi_i(s_i, s_j, x_i, x_j) \equiv s_i \pi_i^S(s_j, x_i, x_j) + (1 - s_i) \pi_i^F(s_j, x_i, x_j) - \frac{\gamma x_i^2}{2} - F(s_i) \quad (17)$$

denote firm  $i$ 's expected overall profit in stage 1, where  $i, j = A, B$  ( $i \neq j$ ), and

$$\begin{aligned} \pi_i^S(s_j, x_i, x_j) &= s_j \tilde{\pi}_i(c - \Delta, c - \Delta) + (1 - s_j) \tilde{\pi}_i(c - \Delta, c - x_j), \\ \pi_i^F(s_j, x_i, x_j) &= s_j \tilde{\pi}_i(c - x_i, c - \Delta) + (1 - s_j) \tilde{\pi}_i(c - x_i, c - x_j). \end{aligned}$$

In stage 1, each firm  $i (= A, B)$  chooses  $s_i$  and  $x_i$  to maximize its expected overall profit,  $\Pi_i(s_i, s_j, x_i, x_j)$ .

There always exists a symmetric equilibrium, i.e.,  $s_A = s_B = s^* \in (0, \theta)$  and  $x_A = x_B = x^* \in (0, X)$ , which satisfy the standard first order conditions,

$$\frac{\partial \Pi_i(s^*, s^*, x^*, x^*)}{\partial s_i} \equiv \frac{\Delta - x^*}{3} \left[ 1 - \frac{(2s^* - 1)(\Delta - x^*)}{6t} \right] - F'(s^*) \equiv G(s^*, x^*; t, \Delta) = 0 \quad (18)$$

$$\frac{\partial \Pi_i(s^*, s^*, x^*, x^*)}{\partial x_i} \equiv \frac{1 - s^*}{3} \left[ 1 - \frac{s^*(\Delta - x^*)}{3t} \right] - \gamma x^* \equiv H(s^*, x^*; t, \Delta) = 0, \quad (19)$$

and the following inequality:

$$\left| \frac{\frac{\partial G(s^*, x^*; t, \Delta)}{\partial x}}{\frac{\partial G(s^*, x^*; t, \Delta)}{\partial s}} \right| < \left| \frac{\frac{\partial H(s^*, x^*; t, \Delta)}{\partial x}}{\frac{\partial H(s^*, x^*; t, \Delta)}{\partial s}} \right|. \quad (20)$$

The inequality holds if the symmetric equilibrium is unique. If there are multiple symmetric equilibria, we find that the inequality holds for extremal equilibria — a class of equilibria often considered for comparative statics in an environment with multiple equilibria.<sup>8</sup> For the purposes of comparative statics, we restrict our attention to  $(s^*, x^*)$  which satisfy (18), (19) and (20).

Now we are ready to explore the effect of competitive pressure on equilibrium level of continuous improvement,  $x^*$ .

**Proposition 4:** There exists a range of parameterizations in which the equilibrium level of continuous improvement decreases as the degree of competitive pressure increases. In particular,  $\frac{dx^*}{dt} > 0$  holds whenever  $\theta < \frac{1}{2}$ .

To understand the effect of competitive pressure on the equilibrium level of continuous improvement, decompose  $\frac{dx^*}{dt}$  as follows:

$$\frac{dx^*}{dt} = \frac{\partial x^*}{\partial t} + \frac{\partial x^*}{\partial s^*} \frac{ds^*}{dt}.$$

Holding  $s^*$  fixed,  $x^*$  decreases as the degree of competitive pressure increases (i.e., as  $t$  decreases) because of the logic analogous to the one presented after Proposition 1. Given  $\frac{\partial x^*}{\partial s^*} < 0$  (by Proposition 3), the direct negative effect of increased competitive pressure on  $x^*$  is reinforced by the impact of  $t$  on  $s^*$ , if  $\frac{ds^*}{dt} < 0$ . That is, if  $\frac{ds^*}{dt} < 0$ , equilibrium probability of success in  $DI$  increases as  $t$  decreases, which further reduces each firm's incentive to invest

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<sup>8</sup>See, for example, pp. 106-7 in Vives (1999) for a discussion of comparative statics on extremal equilibria in context of Cournot competition. Below, we briefly describe the extremal equilibria in context of our framework. Let  $\hat{x}(s; t, \Delta)$  denote the unique value of  $x$  that solves  $\frac{\partial \Pi_i(s, s, x, x)}{\partial x_i} = 0$  for given  $s$ ,  $t$ , and  $\Delta$ . Then,  $G(s^*, \hat{x}(s^*; t, \Delta); t, \Delta) = 0$ . Suppose there are  $K (> 1)$  values of  $s^*$  which satisfy  $G(s^*, \hat{x}(s^*; t, \Delta); t, \Delta) = 0$ . Label those values as  $s^*(1), s^*(2), \dots, s^*(K)$  such that  $s^*(1) < s^*(2) < \dots < s^*(K)$ . Then  $(s^*, x^*) = (s^*(1), \hat{x}(s^*(1); t, \Delta))$  and  $(s^*, x^*) = (s^*(K), \hat{x}(s^*(K); t, \Delta))$  are extremal equilibria. Since  $G(0, \hat{x}(0; t, \Delta); t, \Delta) > 0$  and  $\lim_{s \rightarrow \theta} G(s, \hat{x}(s; t, \Delta); t, \Delta) < 0$ , it follows that at the extremal equilibria,  $\frac{dG(s^*, \hat{x}(s^*; t, \Delta); t, \Delta)}{ds} < 0$ . This in turn implies that  $\left| \frac{\frac{\partial G(\cdot)}{\partial s}}{\frac{\partial G(\cdot)}{\partial x}} \right| > \left| \frac{\frac{\partial H(\cdot)}{\partial s}}{\frac{\partial H(\cdot)}{\partial x}} \right|$ .

in  $CI$ . The condition  $\theta < \frac{1}{2}$  ensures that  $\frac{ds^*}{dt} < 0$ . Note that  $\theta < \frac{1}{2}$  is sufficient but not necessary for continuous improvement to decrease with an increase in competitive pressure. If  $\theta > \frac{1}{2}$ , then it is possible that (i)  $\frac{ds^*}{dt} > 0$ , and consequently (ii)  $\frac{\partial x^*}{\partial s^*} \frac{ds^*}{dt} < 0$ . However, as long as the direct negative effect of competition on  $x^*$  is dominant, i.e.,  $\frac{\partial x^*}{\partial t} > |\frac{\partial x^*}{\partial s^*} \frac{ds^*}{dt}|$ , we still have  $\frac{dx^*}{dt} > 0$ .

As in Proposition 2, we find that the equilibrium level of continuous improvement decreases as the size of discrete innovation increases. To see why, decompose  $\frac{dx^*}{d\Delta}$  as follows:

$$\frac{dx^*}{d\Delta} = \frac{\partial x^*}{\partial \Delta} + \frac{\partial x^*}{\partial s^*} \frac{ds^*}{d\Delta}.$$

Holding  $s^*$  fixed,  $x^*$  decreases as the size of  $DI$  increases because of the logic analogous to the one presented after Proposition 2. This direct negative effect of  $\Delta$  on  $x^*$  is reinforced by the impact of  $\Delta$  on  $s^*$ , if  $\frac{ds^*}{d\Delta} > 0$ . We found that  $\frac{ds^*}{d\Delta} > 0$  holds for all parameterizations. Thus an increase in the size of  $DI$  unambiguously reduce the level of continuous improvement.

## 6 Applying the model to the real-world contexts

This section explores the real-world relevance and usefulness of the model. In particular, we present the findings from our field research at two Japanese manufacturing firms, and demonstrate that our model offers fresh insights on possible mechanisms behind the changing nature of innovation that we observed at these firms. Note that the purpose of this section is not to conduct rigorous empirical tests of the model's theoretical predictions. Given the difficulty of obtaining reliable data on innovation activities within the firm that make a precise distinction between discrete innovation and continuous improvement, rigorous empirical tests are beyond the scope of this paper.<sup>9</sup>

Continuous improvement was once heralded as the hallmark of Japanese manufacturing system; in particular, employees in typical Japanese firms had been strongly encouraged to improve their work methods by actively participating in SGAs (Small Group Activities) such as quality control (QC) circles, Zero Defects, and Kaizen in which small groups at the workplace level voluntarily set plans and goals concerning operations and work together toward accomplishing these plans and goals. However, several recent studies report that Japanese

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<sup>9</sup>For a good example of using case study to enhance the relevance and usefulness of a theoretical model, see Carmichael and MacLeod (2000).

firms appear to have been downplaying the importance of continuous improvement lately.<sup>10</sup> To identify possible causes of the declining focus on continuous improvement in Japan, we conducted detailed field research at two Japanese manufacturing firms, AUTOPARTS and METAL.<sup>11</sup>

We first present findings from our field research in Subsection 5.1, and then discuss applications of our model in Subsection 5.2. We present all our main findings from field research, where some of them are not directly relevant to our model. Reality is quite complex, and we certainly do not claim that our model captures all important aspects of reality. Our model however does capture interconnections among several key field research findings through novel angles, suggesting possible mechanisms behind the declining focus of continuous improvement in these firms. In other words, our model enables us to see important connections of several key changes taking place at these two firms and hence ascertain powerful underlying forces behind each firm's decision to weaken its investment in traditional continuous improvement activities. Thus, we demonstrate the usefulness of our model.

## 6.1 Findings from field research

### 6.1.1 AUTOPARTS

AUTOPARTS is a medium-size unionized manufacturing firm with sales of over 40 billion yen and employment of close to 1200 in 2004. It is a privately-held company with six plants. AUTOPARTS joined a supplier group of a major auto manufacturer, AUTOMAKER in 1949. The tie between the two firms continued to strengthen and by the end of 1980s, over 90 percent of sales of AUTOPARTS went to AUTOMAKER (a supplier group with a strong tie between a manufacturer and its suppliers is often called vertical *keiretsu* in Japan). Specifically AUTOMAKER used a unique type of engine parts which no other auto maker used, and AUTOPARTS was the only firm that supplies such a unique type of engine parts.

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<sup>10</sup>For instance, according to a recent survey conducted by Chuma, Kato and Ohashi (2005), nearly one in two SGA participants believe that SGAs are LESS active now than 10 years ago whereas only 17 percent think SGAs are MORE active now in the industry. Furthermore, the same survey reveals that 30 percent of workers experienced the termination of their small group activities in the last ten years. An extensive case study of the Japanese semi-conductor industry by Chuma (2002) also demonstrates vividly the declining focus on traditional small group activities by Japanese semi-conductor firms.

<sup>11</sup>Our confidentiality agreements with AUTOPARTS and METAL prohibit us from revealing the actual names of these firms.

As such, AUTOPARTS faced little competition in the market for their engine parts. In part due to the overall trend in weakening keiretsu and the increased global competition, however, at the beginning of the 1990s AUTOMAKER decided to weaken its tie to AUTOPARTS, declaring its decision to switch gradually from the unique type of engine parts to the universal type of engine parts which not only AUTOPARTS but also many other auto part suppliers produce. AUTOMAKER began telling AUTOPARTS that they may start buying engine parts from other suppliers and that AUTOPARTS is encouraged to sell its products to other auto manufacturers. As a result of the weakening tie between the two firms, in 2004, close to 30 percent of AUTOPARTS' sales went to other auto makers (a considerable rise from less than 10 percent at the end of the 1980s).

While leaving a cocoon of keiretsu in the 1990s and facing more competition, the nature of innovation in AUTOPARTS changed considerably. AUTOPARTS used to have effective small group activities of operators with small, incremental process improvements. In the 1990s, such small group activities became less effective and active. Specifically, as competition intensified, AUTOPARTS introduced more sophisticated, advanced and expensive technologies. Some of these technologies are exceedingly sophisticated and expensive that even experienced engineers of AUTOPARTS are discouraged to attempt to tinker with them. As such, there is no room for onsite incremental improvements on such technologies and hence no small group activities of operators are used in their workplaces with such technologies. In fact, AUTOPARTS filled most new openings for operator positions in their workplaces using such advanced technologies with migrant workers from Brazil. Since nearly all of these migrant workers from Brazil speak only Portuguese, even if AUTOPARTS decide to introduce small group activities to these workplaces, it will be prohibitively costly to run such bilingual small group activities. At the time of our most recent visit to AUTOPARTS (July of 2005), there are around 900 regular employees and about 300 temporary employees with fixed-term contracts. Almost all of these 300 temporary employees are migrant workers from Brazil.<sup>12</sup>

Many traditional operator-oriented small group activities have been replaced with “technology groups.” Such technology groups are comprised of professional staff (such as engineers) and they specialize in process innovation. This represents an example of a shift from bottom-

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<sup>12</sup>These migrant workers from Brazil are Brazilians of Japanese decent, and since the 1989 revision of the Immigration Control and Refugee recognition Act, such foreigners of Japanese decent have been exempt from regular restrictions imposed on foreign visitors (Ogawa, 2005).

up, operator-initiated, voluntary, self-directed problem solving team activities to top-down, engineer-initiated, involuntary problem solving group activities of process innovation specialists. Note that we observed a similar shift in METAL, as described below.

At the same time, AUTOPARTS has been faced with an increased need for developing attractive products. Traditionally AUTOPARTS receives from AUTOMAKER detailed specifications for specific engine parts used by AUTOMAKER, and sales of such parts to AUTOMAKER are guaranteed. In recent years, however, with the weakening role of keiretsu in Japan, AUTOMAKER demands AUTOPARTS to develop attractive products for them, and sales of their products to AUTOMAKER are no longer guaranteed. To respond to the enhanced need for product development, AUTOPARTS has been actively recruiting engineers with 4-year degrees in the last two decades. The number of engineers working in product development has increased from 20 to 53 in the last decade.

### **6.1.2 METAL**

METAL is a large unionized manufacturing firm with sales of over 400 billion yen and employment of close to 4,000 workers in 2005. It is listed in the first section of Tokyo Stock Exchange. The corporation has nine plants. There have been four important changes at METAL in the last two decades which are relevant to their activities to facilitate continuous improvement and promote discrete innovation. First, Chinese firms have been taking over the lower end of the product line of METAL. For example, METAL has been called “the department store of specialty metal” and well-known for its comprehensive product line supplying nearly all kinds of specialty metal to major users of such metal (such as auto manufacturers). As a result of increased competition mostly coming from Chinese firms, in recent years, METAL has been shifting its strategy from “all-round utility player” to “specialty player” focusing on the high end of the product line. A key component of this new strategy is to develop “NO. 1 product” or “Only one product”. For example, METAL has been working on developing a new high-quality, high-performance specialty metal used for jet engine while accelerating its exit from a line of more traditional low-cost metal.

Second, METAL has been experiencing a shortening cycle of their product in recent years. For example, METAL and a major auto manufacturer used to develop a new specialty metal (which a transmission will be made of) jointly under an implicit long-term (typically 2 years) contract which guarantees the eventual sale of the product to the auto manufacturer.

In recent years, such long-term implicit contracts have been replaced with short-term (a few months) contracts with no guarantee for repeated transactions. As such, product cycles are now in months not in years. Another example is a new product area such as magnetic material and metal powders where METAL has been moving into lately. Users of such a new product area are closer to final consumers than traditional specialty metal users, and there are so many more competitors. As such, the market is closer to a short-term spot market than a relational long-term contract market.

Third, rapid retiring of seasoned operators who are fully capable of engaging in traditional bottom-up, self-directed problem solving activities, coupled with the recent downsizing of such operators, makes continuous improvement less effective.

Fourth, the nature of their small group activities, a hallmark of their grassroots innovation activities, has been changing from “bottom-up, operator-centered activities within the workplace” to “more top-down, more engineer-centered, cross-functional offline activities across workplaces.” Specifically, METAL’s small group activities began in 1967. As in the case of many traditional small group activities in large Japanese firms, METAL’s small group activities started out as “voluntary” offline problem solving teams in which front-line workers meet normally after regular hours and “voluntarily” engage in problem solving activities with no or only token compensation. METAL called their small group activities “self-directed team activities” and stressed the importance of operator initiative in selecting themes, setting goals, scheduling meetings, writing up final reports and presenting them. It was clearly meant to be bottom-up, operator-initiated activities at the shopfloor level. It followed that their activities tended to focus on small, incremental problem solving within the shopfloor.

METAL made two major changes to their traditional “self-directed team activities” and increased the level of involvement of professional staff (engineers and managers) and changed the nature of problem solving from small, incremental improvements within the narrow workplace to larger and more discrete innovation involving multiple workplaces. First, in mid-1990s, METAL introduced a new type of small group activities, WANTED. Professional staff comes up with a specific theme (a problem to be solved), and ask a “self-directed team” to volunteer to take it up. Before the introduction of WANTED, all problems to be solved were set by operators. Within a few years after the introduction of WANTED, only about a half of all completed themes were set by operators and the rest were set by professional staff. Accordingly the nature of problem solving shifted from small and incremental improvements



within the shopfloor to larger and discrete innovation involving multiple shopfloors. METAL estimated that the amount of productivity gain from problem solving by their self-directed team activities also doubled per activity a few years after the introduction of WANTED.

Second, in September 2004, METAL identified 7 workplaces out of 80 as target workplaces. These target workplaces were chosen mainly because of their known productivity problems. METAL then allocated considerable amount of money and professional staff to those target workplaces with a specific goal of 30 percent increase in productivity in 6 to 12 months. Most importantly METAL assigned key engineers from various parts of the firm to each of those seven target workplaces and such engineers initiated a variety of problem solving activities with operators in each target workplace. Due to the relatively short time span (6-12 months) and hefty goal (30 percent increase in productivity), those engineer-initiated problem solving activities were distinctly different from typical self-directed team activities. They tended to go after bigger innovation by using more resources (money and professional staff) than traditional self-directed team activities. By the time of our more recent visit to METAL (June of 2005), 5 out of 7 target workplaces had already achieved their goal of 30 percent productivity increase.

## **6.2 Applications of the model**

By applying the model to the findings from our field research, we illustrate the real-world relevance and usefulness of our model and demonstrate the distance of our model from the previous ones. Consistent with the overall trend in Japanese manufacturing firms, we have observed that the level of continuous improvement has been declining at both firms. The declining trend was clear at AUTOPARTS, while it was more subtle at METAL. That is, METAL's small group activity itself continues to be active, but the nature of problem solving undertaken by small groups has shifted its focus to larger and more discrete innovation involving multiple workplace from small, incremental improvements within the narrow workplace. Note that it could have been difficult to identify such a subtle change without detailed field research.

Why have the levels of continuous improvement declined at these firms? Below we will explore this question by applying our model to field research findings. Since AUTOPARTS and METAL are intermediate-goods producers, we consider the model developed in Subsection 4.3. Let us start from AUTOPARTS. The level of continuous improvement in AUTOPARTS

has drastically declined in the 1990s. The reason for this drastic decline, as we were told in our interview, was AUTOPARTS's introduction of more sophisticated and advanced production system for which continuous improvement is virtually impossible. However, we have also found that this type of production system had been available for a number of years before the company actually introduced them. Why, then, did AUTOPARTS introduce the new system at that particular timing?

AUTOPART's main customer is AUTOMAKER, while there are several other suppliers of engine parts that have different main customers. Keeping this in mind, in our model we interpret Supplier  $A$  as AUTOPARTS and Supplier  $B$  as its competitor where they produce different varieties of the engine part. On the demand side, we interpret each final-good producer  $y$  ( $\in [0, 1]$ ) as a plant of an automobile manufacturer, and assume that there are two automobile manufacturers, Manufacturer  $A$  and  $B$ . We capture the idea that Manufacturer  $i$  is the main customer of Supplier  $i$  by assuming that Manufacturer  $A$  has a continuum of plants represented by the left half of the line segment between 0 and  $1/2$ , and Manufacturer  $B$ 's plants are represented by the right half of the line segment.

In this set-up, we analyze the way in which a change in product substitutability of the engine parts affects the strength of the tie between Supplier  $i$  and Manufacturer  $i$  ( $= A$  or  $B$ ). We find that there exists a unique threshold  $z^* \in [0, 1/2]$  such that, in the equilibrium, (i) if both Suppliers  $A$  and  $B$  succeed or fail in  $DI$ , then each Supplier  $i$  serves all plants of Manufacturer  $i$  ( $i = A, B$ ), and (ii) if Supplier  $i$  succeeds while Supplier  $j$  fails in  $DI$  ( $i, j = A, B, i \neq j$ ), then Supplier  $i$  serves all plants of Manufacturer  $i$  and  $z^*$  plants of Manufacturer  $j$  while Supplier  $j$  serves  $1/2 - z^*$  plants of Manufacturer  $j$ , where  $z^*$  is strictly decreasing in  $t$  for all  $F < F''$ .<sup>13</sup> Each Manufacturer  $i$  ( $= A$  or  $B$ ) is Supplier  $i$ 's main customer in the sense that, on average, majority of Manufacturer  $i$ 's plants are served by Supplier  $i$ . However, as  $t$  decreases, an increasing fraction of Manufacturer  $i$ 's plants are served by Supplier  $j$  when Supplier  $j$  succeeds and Supplier  $i$  fails in  $DI$ . That is, our model predicts that the tie between each Supplier  $i$  and Manufacturer  $i$  becomes weaker as the degree of product substitutability of the engine parts increases.<sup>14</sup>

Recall that AUTOPARTS faced a higher degree of competition in the beginning of the 1990s due to the change of AUTOMAKER's procurement policy. In particular, AU-

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<sup>13</sup>If  $F \geq F''$ , then neither supplier invests in  $DI$  in the equilibrium, and hence  $z^*$  is not relevant to the analysis.

<sup>14</sup>Details of the analysis are available upon request.

TOMAKER switched gradually from the unique type of engine parts supplied only by AUTOPARTS to the universal type of engine parts which not only AUTOPARTS but also many other auto part suppliers produce. A similar change of procurement policy took place in many other automobile manufacturers about the same time in Japan, and this trend is often referred to as “weakening of vertical *keiretsu*”.<sup>15</sup>

In our model, this change can be captured by an increase in the product substitutability of the engine part; that is, a reduction in  $t$ . Our model predicts that the tie between each Supplier  $i$  and Manufacturer  $i$  becomes weaker as the product substitutability increases, and this is consistent with what happened between AUTOPARTS and AUTOMAKER in the early 1990s. As mentioned earlier, a robust finding in previous theoretical analyses is that an increase in competitive pressure measured by product substitutability increases deterministic investment in cost reduction (i.e., continuous improvement). In contrast, our model indicates that the interplay between discrete innovation and continuous improvement can reverse the result, predicting that an increase in product substitutability decreases the equilibrium level of  $CI$  when  $F \leq F'$  (Proposition 1). When  $F > F'$ , the model yields the same prediction as long as an increase in product substitutability increases  $\sigma^*$ , the equilibrium probability for each supplier to invest in  $DI$ . Furthermore, when the success probability of  $DI$  is endogenized, the model yields the same prediction as long as an increase in product substitutability increases  $s^*$  (Proposition 4). And the recent drastic increase in the number of engineers working in product development suggests that AUTOPART has increased its investment in  $DI$ , indicating higher  $\sigma^*$  or  $s^*$ .

Our model therefore indicates that the increase in product substitutability of the engine parts, which took place in Japanese automobile industry in the early 1990s, can be a root cause of the drastic decline in the level of AUTOPART’s continuous improvement. That is, a possible scenario is that the higher degree of product substitutability reduced AUTOPARTS’s return from continuous improvement on the existing production system, which in turn induced AUTOPARTS to introduce the new production system upon which continuous improvement is virtually impossible.

Next we turn to METAL, which has changed the focus of its small group activity from

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<sup>15</sup>The “weakening of vertical keiretsu” is by now a widely-held view in Japan (see, for instance, Japan Small Business Research Institute, 2007). For quantitative evidence, for instance, see Ahmadjian and Robbins (2005). Fujiki (2006) provided an intriguing “insider” account of the change in the vertical keiretsu relationships in the auto-manufacturing industry.

traditional self-directed kaizen activities aimed at small incremental improvement within the narrow workplace to large-scale, engineer-initiated activities involving multiple workplaces with a clear objective of more discrete innovation. Why has the level of continuous improvement declined in METAL? Below we explore this question through applying our model to the case of METAL. The specialty metal industry consists of several producers including METAL and a number of customers who produce final products from specialty metal. Since customers produce a variety of different final products, ideal product characteristics of specialty metal differ across customers. Keeping this in mind, in our model we interpret Supplier *A* as METAL and Supplier *B* as its domestic competitor (i.e. another specialty metal producer in Japan) where they produce different varieties of the specialty metal. On the demand side, we interpret each final-good producer  $y \in [0, 1]$  as an independent firm that procures the speciality metal from Supplier *A* or *B*.

Recall that, as a result of increased competition mostly coming from Chinese firms, METAL has been shifting its strategy from “all-round utility player” to “specialty player” focusing on the high end of the product line. We incorporate this shift into the analysis of our model under the following suppositions: (i) Similar shifts have been taking place in other Japanese specialty metal producers, and (ii) the return of discrete innovation for high-end products is higher than that for low-end products. The first supposition is plausible, given that the shift taking place in METAL is driven by the competition from Chinese firms which should have similar impacts on other Japanese specialty metal producers. Concerning the second supposition, METAL’s increased focus on high-end products often meant that the market for such products was still relatively unexplored and that discrete innovation in such high-end products when succeeded allowed METAL to carve out a significant share of the market. During our field visits to METAL, we discovered several examples of such successful discrete innovation. METAL started to devote its financial and human resources to new product developments only in the 1990s. For each promising new product idea, METAL created a section in its R&D department. Each section consisting of a few engineers plus operators tried out the new product idea. Many failed yet some succeeded. When failed, METAL closed the failing section. When succeeded, METAL selected a plant suitable for the production of the new product and created a new product line within the plant (often led by those engineers and operators in the original section of the R&D department). Such new product lines often expanded over time and became significant sources of profit. Most recently, METAL’s new product developments even went beyond its familiar speciality metal

field by successfully developing ultra-thin disc magnet (METAL now has a new department producing magnet in its brand new plant). In short, it is conceivable that discrete innovation in high-end products may be risky yet when successful, it tends to yield higher return than that in low-end products.

Since Suppliers  $A$  and  $B$  are interpreted to be Japanese specialty metal producers, the increased competition coming from Chinese firms can be treated as an exogenous factor to the model. In response to this, both producers have shifted their focus on high-end products, which exhibit higher returns from discrete innovation. Noting that, in steel manufacturing processes, a variety of different products ranging from high-end products to low-end products are produced in the same production facility, increasing weight of high-end products increases  $\Delta$  at aggregate levels. Given this, we suppose that  $\Delta$  has recently increased in Japanese specialty metal industry.

Our model and its extension considered in Section 5 both predict that an increase in  $\Delta$  reduces the equilibrium level of  $CI$ . That is, our model proposes a hypothesis that the shift of METAL's strategy to the high-end products can be a driving force of METAL's declining focus on continuous improvement.

One might argue that the nature of discrete innovation for high-end products is not only higher return but also higher risk than that for low-end products. That is, in the context of our model, in addition to  $\Delta$  being higher,  $s$  (the success probability of  $DI$ ) could be lower in our base model or the cost for  $DI$ ,  $F(s)$ , could be higher for any given  $s$  in the extension consider in Section 5, for high-end products. Even if the risk associated with  $DI$  has recently increased in Japanese specialty metal industry, an increase in  $\Delta$  still reduce the equilibrium level of  $CI$  as long as  $s\sigma^*$  in our base model or  $s^*$  in the extension has increased. Recall that METAL has been experiencing a shortening cycle of their product in recent years. In the context of our model, the product-life cycle becomes shorter, in an expected sense, as the overall success probability of  $DI$  (that is,  $s\sigma^*$  or  $s^*$ ) increases. Therefore, in the “higher-risk higher-return” scenario of high-end products, our model indicates that the shift of METAL's strategy to the high-end products, along with its shortening product-life cycle, can be a driving force of METAL's declining focus on continuous improvement.

In sum, we have illustrated possible ways in which our model can be applied to real-world contexts and provide fresh insights on the causes of the diminishing focus on continuous improvement that was once heralded as the hallmark of the Japanese enterprise system. Specifically, in our model, an increase in competitive pressure reduces the equilibrium level

of  $CI$ , and an increase in the return from  $DI$  also reduces the equilibrium level of  $CI$ . These theoretical predictions suggest possible reasons for the decline in continuous improvement at AUTOPARTS and METAL, respectively. The interplay between discrete innovation and continuous improvement in the presence of competitive pressure suggests novel underlying mechanisms behind the changing nature of innovation at these firms.<sup>16</sup>

## 7 Conclusion

In studying a possible linkage between firms' innovation incentives and competitive pressure, prior studies ignored a distinction between *discrete innovation* aiming at entirely new technology and *continuous improvement* consisting of numerous incremental improvements and modifications made upon the existing technology. In this paper, we have demonstrated that distinguishing between these two types of innovation will lead to a much richer understanding of the interplay between firms' incentives to innovate and competitive pressure. As such, we have provided novel insights on the sources and nature of technical progress.

Specifically, we have considered a Hotelling style duopoly model in which firms' locations are fixed. Each firm makes decisions concerning its investment in discrete innovation, and continuous improvement on the existing technology. Discrete innovation generally involves more significant uncertainty than continuous improvement. There is, however, an important risk with continuous improvement. Various improvements and modifications made on the existing technology will be nullified by the very success of discrete innovation. In other words, when deciding on its innovation strategy, the firm will take into consideration the negative consequence on continuous improvement of the very success of discrete innovation.

Our model has yielded several new predictions. We have found that the equilibrium level of continuous improvement declines as the degree of competitive pressure increases. This is in contrast to the previous results in the theoretical industrial organization literature: The robust findings have been that an increase in competitive pressure measured by product substitutability increases firms' investment in continuous improvement. The difference arises due

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<sup>16</sup>Several alternative hypotheses could also be developed concerning causes of the changing nature of innovative activities at AUTOPARTS and METAL. For example, rapid retiring of seasoned operators who are fully capable of engaging in traditional bottom-up, self-directed problem solving activities, coupled with the recent downsizing of such operators, may be an important driving force of the declining focus of METAL's continuous improvement.

to the aforementioned interplay between continuous improvement and discrete innovation in the presence of competitive pressure, which is uniquely captured by our model. Another new theoretical prediction is that firms' incentives to conduct continuous improvement declines as the size of discrete innovation increases.

To demonstrate the relevance and usefulness of the model, we have applied these theoretical predictions to the findings from our field studies conducted at two Japanese manufacturing firms, AUTOPARTS and METAL. Continuous improvement was once heralded as the hallmark of Japanese manufacturing system. However, several recent studies report that Japanese firms appear to have been downplaying the importance of continuous improvement lately. Consistent with the overall trend, we have observed that the level of continuous improvement has been declining at both firms.

Through capturing the interplay between discrete innovation and continuous improvement in the presence of competitive pressure, our model has suggested novel underlying mechanisms behind the changing nature of innovation at these firms. At AUTOPARTS, we have observed that the firm has been exposed to much tougher competition with its rivals, and our model indicates that the tougher competition can be a root cause of the drastic decline in AUTOPART's continuous improvement. At METAL, we have observed that the firm has been shifting its strategy from all-round utility player to specialty player focusing on the high end of the product line. Given that return from investment in discrete innovation tends to be higher for high-end products, our model indicates that this trend can be a driving force of METAL's declining incentive to invest in continuous improvement.

Our framework can be applied to broader and more general real-world contexts. For example, competitive pressure has increased in a number of Japanese industries in the recent trend of globalization and deregulation. Our model predicts that the increase in competitive pressure can be an important cause of the recent decline in the level of Japanese firms' continuous improvement. In a future work, we plan to conduct intensive data collection for rigorous econometric tests of this prediction.

## 8 Proofs

[More materials to be incorporated soon.]

**Proof of Proposition 1:** Expanding (8) gives  $x^* = \frac{(1-s)(3t-s\Delta)}{9t\gamma-s(1-s)}$  if  $\Delta < 3t + \frac{(1-s)^2}{3\gamma}$  and  $x^* = \frac{(1-s)^2}{3\gamma}$  if  $\Delta > 3t + \frac{(1-s)^2}{3\gamma}$ . Define  $\bar{\Delta} \equiv 3t + \frac{(1-s)^2}{3\gamma}$ . For  $\Delta < \bar{\Delta}$ , we have that  $\frac{dx^*}{dt} =$

$\frac{9\gamma s(1-s)(\Delta - \frac{1-s}{3\gamma})}{(9t\gamma - s(1-s))^2}$ . Since  $X - \frac{1}{3\gamma} > 0$  (by footnote 3) and  $\Delta > X$  we have that  $\Delta - \frac{1-s}{3\gamma} > 0$  which in turn implies that  $\frac{dx^*}{dt} > 0$  for  $\Delta < \bar{\Delta}$ . If  $\Delta > \bar{\Delta}$ ,  $\frac{dx^*}{dt} = 0$  since  $x^*(= \frac{(1-s)^2}{3\gamma})$  is independent of  $t$ . *Q.E.D.*

**Proof of Proposition 2:** If  $\Delta < \bar{\Delta}$ ,  $\frac{dx^*}{d\Delta} = -\frac{s(1-s)}{9t\gamma - s(1-s)} < 0$ . If  $\Delta > \bar{\Delta}$ ,  $\frac{dx^*}{d\Delta} = 0$  since  $x^*(= \frac{(1-s)^2}{3\gamma})$  is independent of  $\Delta$ . *Q.E.D.*

**Proof of Proposition 3:** If  $\Delta < \bar{\Delta}$ ,  $\frac{dx^*}{ds} = -\frac{(3t-s\Delta)(9t\gamma - (1-s)^2) + \Delta(1-s)(9t\gamma - s(1-s))}{(9t\gamma - s(1-s))^2}$ . By footnote 3,  $9t\gamma - 1 > 0$ . Hence  $9t\gamma - (1-s)^2 > 0$  and  $9t\gamma - s(1-s) > 0$ . Finally, since  $3t - s\Delta > 3t - s\bar{\Delta}(\equiv \frac{(1-s)(9t\gamma - s(1-s))}{3\gamma}) > 0$  we have that  $\frac{dx^*}{ds} < 0$ . If  $\Delta > \bar{\Delta}$ ,  $\frac{dx^*}{ds} = -\frac{2(1-s)}{3\gamma} < 0$ . *Q.E.D.*

**Proof of Proposition 4:** To be typed up soon.



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