Temporary Protection and Technology Choice under the Learning Curve

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This paper examines the effects of temporary protection in a model of international Cournot competition under the learning curve. We show that when the protected firm can choose among multiple technologies subject to different scopes for learning, the positive relationship between current production and learning cannot be relied upon. The protection may hurt the long-run competitiveness of the domestic firm, decreasing its future sales both in the home market and in the foreign market.

Key words: Temporary Protection; Learning; Technology Adoption; Infant Industry
JEL classification: F12, F13

I. Introduction

Suppose we have a typist who works for predetermined wages. He has been using a word-processing software, of which he now is a master. He is considering switching to a new one. The new one has a greater productive potential. However, adopting it will reduce his productivity temporarily because he has to look up help whenever he performs a new task. Only when he becomes sufficiently experienced will he be able to realize its potential advantage. Thus, to assess the desirability of a switch, he has to weigh the benefit of enhanced productivity in the long run against the cost of reduced productivity in the short run.

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Suppose he experiences a temporary surge in his work load. Will it increase his incentive to switch? With more pages to type, he has more opportunity for learning the new software. The long-run benefit of adopting the new software increases. However, his work load now is concentrated on the current period, during which he is more productive with the old software than with the new software. This raises the short-run cost of switching to the new software. The answer to the question would depend on which of the two effects dominates.

International economics has a long history of analyzing the relationship between protection and learning. A typical assumption made is that higher output now reduces the cost of production later as a producer acquires additional knowledge through experience. Thus, protection, even when it is only temporary, enhances the long-run competitiveness of protected firms by boosting up their production now. At the center of the time-honored and influential argument for infant industry protection lies this crucial nexus between production and learning.

An implicit assumption underlying infant industry protection is that firms in the protecting country have a lot to learn from using the current technology. This assumption would be valid in cases where the protected industry is entirely new to the protecting country. However, as for many industrializing countries seeking a rationale for temporary protection or delayed liberalization, the assumption is often questionable. Frequently, the industry in question has been there and domestic firms have been using the current technology for some time, even though it is less efficient than the one used by their foreign competitors. This is also true in the case of advanced countries that are considering temporary protection to earn time to catch up with their foreign competitors. In this situation, protected firms may have little to learn from producing more with the current technology.

This paper argues that the relationship between production and learning is non-monotonic in the presence of multiple technologies subject to differential scopes for learning. The argument rests on the following assumptions. Firms have little to learn from repeating the current production process. Only with a new technology will practice and experience generate a significant amount of learning. However, a new technology, though it has a greater productive potential, initially is inferior to the older one.[2]

We explore the implications of these assumptions for the effects of temporary protection in a model of international Cournot duopoly. The model is similar to the two-period models of learning-by-doing presented by Spence (1981) and Fudenberg and Tirole (1983). The difference is that we consider the choice of technology simultaneously with learning in an infant-industry setting. A foreign firm is using a new technology whose productive potential has already reached a maximum. A domestic firm faces a choice between an old technology with its learning potential exhausted and a new technology with a steep learning curve, but initially inferior to the older one.

In this setting, we show that protection imposed only for period 1 can reduce the protected firm's incentive to adopt the new technology. Just as in the typist example above, the temporary surge in demand caused by protection makes the new technology more attractive as it allows the firm to learn faster about the new technology. However, it also raises the relative importance of having low costs now compared to having low costs in the future, making the new technology less attractive. If the latter effect dominates, temporary protection increases the firm's incentive to stick to the old technology, while it stimulates current output.

The argument of this paper, on several aspects, is reminiscent of the case against infant-industry protection made by Baldwin (1969), who argues that protection is an ineffective means of stimulating learning in the presence of problems in appropriating

[2] For a justification of these assumptions based on historical episodes, see Young (1993).

knowledge. Recently, Miyagiwa and Ohno (1995, 1999) demonstrate the possibility that temporary protection delays innovations when credibility problems exist regarding the duration of protection. This paper differs from these studies in that our argument has no relation with the appropriation or the credibility problem.

The specification of technology adopted by this paper is closely related to the recent literature on endogenous growth theory (Young 1993, Lucas 1993 and Parente 1994). These papers examine the interactions between learning and technology adoption under the assumption that any given technology has bounded productivity and a switch of technologies temporarily reduces human capital. However, these papers suggest that an increase in the market size speeds up technological progress, ignoring the possible negative relationship between production and learning. The model closest in spirit is that of Jovanovic and Nyarko (1996). In a one-agent Bayesian model, they show the possibility that an agent who is so experienced in the current technology will never switch, while an agent who is less experienced will keep switching to better technologies. In this paper, too much protection replaces the role of too much experience in their model.

This paper is organized as follows. Section II presents the model. Section III discusses possible extensions. Section IV concludes.

II. The Model

There are two firms competing in a home market -- one is domestic and the other is foreign.[3] The two firms produce a homogenous good and engage in Cournot competition over two periods. The inverse demand function of the market is given by $p(z)$, where z is industry output. $p(z)$ is continuously differentiable and $p'(z) < 0$.

There are two CRS technologies available for the industry -- one is old and the

[3] I assume that the domestic firm does not export. This assumption will be relaxed in section III.

other is new. The foreign firm has been using the new technology for some time, and as in most analyses of an infant industry, we assume that its learning has ceased. Thus its unit cost is fixed at c^* for both periods. In contrast, the domestic firm has been producing with the old technology. If it continues to use to the old technology in period 1, the unit cost is given by $\bar{c}$ for both periods. If it switches to the new technology in period 1, paying the fixed price of F, the unit cost in period 1 is given by c, which is greater than $\bar{c}$. The firm can now learn from experience and the unit cost in period 2 decreases as it produces more in period 1. This relationship is represented by the learning curve $l(x)$, where x is the output in period 1 and $l(x)$ is the unit cost in period 2. Naturally, $l(0) = c$ and $l'(x) < 0$. I will assume that $l''(x) > 0$ and $l(x)$ approaches a positive number strictly less than $\bar{c}$ as x approaches infinity. The learning has diminishing returns and is bounded.

The game will proceed as follows. In each period, each firm simultaneously chooses a technology *and* output.[4] The foreign firm always uses the new technology. The domestic firm has to decide on whether to produce with the old technology or with the new one.[5] If it uses the old technology in period 1, then it will continue to use the old one in period 2. If it adopts the new technology in period 1, it will continue to use the new one in period 2 on the condition that $l(x)$ is less than $\bar{c}$.[6] We will solve the game for a subgame-perfect Nash equilibrium by backward induction.

For the second-period game, note that the outcome depends on the unit costs of the two firms, which are predetermined in period 1. Since the unit cost of the foreign

[4] Changing the game structure such that the firms choose a technology before they choose the level of output does not fundamentally alter the results.

[5] I will assume that the domestic firm only operates a single technology. The consequence of relaxing this assumption will be discussed in section III.

[6] In the following, I will assume that this condition is always met. If not, the firm never adopts the new technology in period 1. Thus this case can be safely ignored in search of an equilibrium

firm is fixed at c^*, we can express the profit of the domestic firm in period 2 as $\pi_2(c_2)$[7], where c_2 is the unit cost of the domestic firm in period 2 and π_2 is decreasing in c_2.

Now, go to the first period game. Suppose the domestic firm expects that the foreign firm will produce y in period 1. For the old technology, the domestic firm solves the following problem.

$$\bar{V}(y) \equiv \underset{x}{\text{Max}}\,(p(x+y) - \bar{c})\,x + \pi_2(\bar{c}). \tag{1}$$

I will use bars to denote quantities associated with the old technology. For the new technology, the domestic firm solves the following problem.

$$V(y) \equiv \underset{x}{\text{Max}} \quad (p(x+y) - c)\,x + \pi_2(l(x)). \tag{2}$$

The domestic firm will adopt the new technology if and only if $V(y) - \bar{V}(y) \geq F$.

From equation (1), the first order condition for maximizing $\bar{V}$ is given by

$$p(x+y) + p'(x+y)\,x = \bar{c}. \tag{3}$$

This equation implicitly defines the best response of x under the old technology as a function of y. Let us denote this function as $\bar{r}(y)$. From equation (2), the first order condition for maximizing V is given by

$$p(x+y) + p'(x+y)\,x = c - \pi_2'(l(x))\,l'(x). \tag{4}$$

The marginal revenue is equated to the dynamic marginal cost, which is equal to the current marginal cost less the increase in the second-period profit due to additional

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[7] π_2 can be interpreted as the present value of the second-period profit. To guarantee the differentiability of this function, I will assume that c_2 is in such a range that neither firm supplies the whole market in period 2.

learning. We will denote the dynamic marginal cost by $\tilde{c}(x)$. Equation (4) defines the best response of x under the new technology, which will be expressed by $r(y)$.

To guarantee the optimality of the response functions, let us impose the following second-order conditions. As usual in the analysis of Cournot competition,

$$p'(x+y) + 2\,p''(x+y)\,x < 0, \qquad (5)$$

$$p'(x+y) + p''(x+y)\,x < 0 \qquad (6)$$

for all non-negative x and y. In other words, the marginal revenue curve is downward sloping and it shifts to the left when the rival's output increases. The parallel assumption is also made for the foreign firm. In addition, we assume that

$$\tilde{c}'(x) > 0. \qquad (7)$$

The dynamic marginal cost is increasing in x. The increases in the future profit due to additional learning are diminishing.[8] The new technology will never be adopted if $\tilde{c}(0)$ is greater than $\bar{c}$. In addition, as x increases and the learning approaches a limit, $\tilde{c}(x)$ goes to c. This property of $\tilde{c}(x)$ is illustrated in figure 1.

The analysis of the game can be divided into several possible cases, depending on the relative sizes of the market and the unit costs. To avoid being typological, I will focus on the most interesting one. The other cases can be easily worked out using the same method. Suppose the market is sufficiently large that the marginal revenue curve of the domestic firm corresponding to a sufficiently low value of y, say y_0, is located at $MR(y_0)$ in the lower panel of figure 1. The marginal effect of learning is low and $\tilde{c}(x)$ is above $\bar{c}$. Thus $r(y_0) < \bar{r}(y_0)$. As y increases, the marginal revenue curve shifts to the left and both r and $\bar{r}$ decrease. At y_1, the marginal revue curve passes through the

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[8] This assumption is stronger than necessary. It can be replaced by the assumption that $\tilde{c}(x)$ cuts the marginal revenue curve from below and it meets only once the $\bar{c}$ line in figure 1.

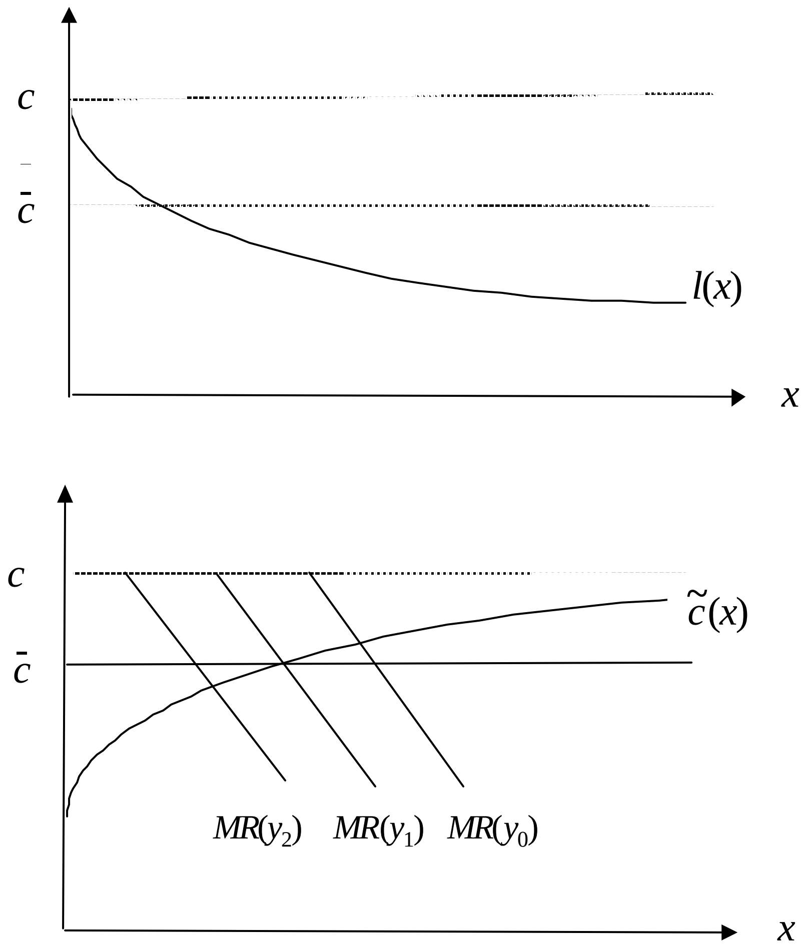

Figure 1

Diminishing Marginal Learning

intersection point of $\tilde{c}(x)$ and $\bar{c}$, and $r(y_1) = \bar{r}(y_1)$. If y increases further to y_2, then the marginal effect of learning becomes high, making $\tilde{c}(x)$ less than $\bar{c}$. Thus $r(y_2) > \bar{r}(y_2)$. These responses of the domestic firm are traced out in the upper panel of figure 2.

To see how the incentive for adopting the new technology changes as y changes, let us define $D(y)$ as $V(y) - \bar{V}(y)$. Differentiating $D(y)$ with respect to y,

$$D'(y) = V'(y) - \bar{V}'(y)$$
$$= p'(r(y)+y)\, r(y) - p'(\bar{r}(y)+y)\, \bar{r}(y).$$

I applied the envelope theorem to equations (1) and (2). By equation (6), $p'(x+y)\,x$ is

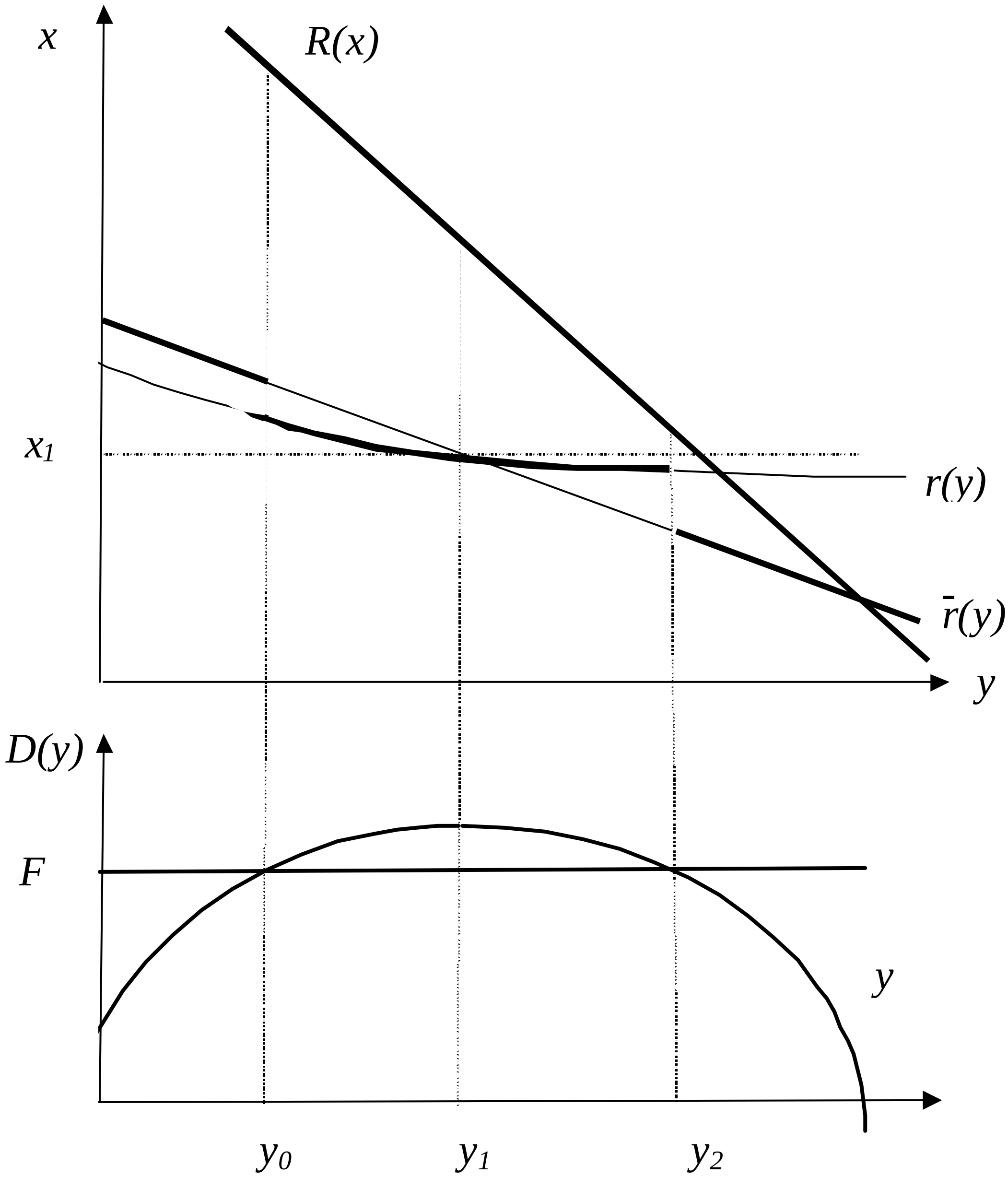

Figure 2

The Choice of Technology

decreasing in x. Thus, $D'(y)$ exceeds 0 if and only if $r(y) < \bar{r}(y)$. The lower panel of figure 2 shows how $D(y)$ depends on y.

Now we derive the global response of the domestic firm. The domestic firm chooses the new technology if and only if $D(y)$ is greater than F. An interesting case is illustrated in the lower panel of figure 2. At this value of F, the domestic firm chooses the new technology for $y \in [y_0, y_2]$. Thus, $r(y)$ is the best response in this range. Outside this range, $\bar{r}(y)$ is the best response. Thus, the best response curve of the domestic firm is given by the bold curve in the upper panel of figure 2.

The Cournot-Nash equilibrium is determined at the intersection point of the domestic best response curve and a foreign best response curve. (As is obvious from figure 2, there is a possibility of multiple equilibria.) Suppose that the unit cost of the foreign firm is so low that the foreign best response $R(x)$ is located at the far right in the upper panel of figure 2. Under free trade, the domestic firm chooses the old technology. Suppose the government imposes a binding quota only for period 1. The foreign best response curve becomes kinked at the level of the quota, which I will call q.[9] As long as q is greater than y_2, the domestic firm chooses the old technology. In this range of q, a temporary quota does not affect the outcome in period 2. It just decreases the output of the foreign firm and increases that of the domestic firm in period 1. If q is less than y_2, the domestic firm switches to the new technology. Now the quota has repercussions in period 2. As the domestic firm's unit cost decreases from $\bar{c}$ to $l(r(q))$ in period 2, the output of the foreign firm falls and that of the domestic firm rises in period 2, when there is no more protection. The temporary protection increases the future competitiveness of the domestic firm and decreases future imports.

However, we can easily have the opposite results. Suppose the position of the foreign best response curve is such that the equilibrium output of the foreign firm under free trade is between y_0 and y_2. The domestic firm selects the new technology under free trade. However, if the government imposes a temporary quota whose level is below y_0, the domestic firm selects the old technology. The second-period unit cost of the domestic firm under the protection is given by $\bar{c}$, which is higher that the one that

[9] If the government imposes a temporary tariff, the foreign best response curve shifts to the left and the effect is similar. The only difference is that the possibility of multiple equilibria increases.

would have prevailed under free trade. The temporary protection decreases the long-run competitiveness of the domestic firm even though it increases the current output of the domestic firm. It lowers future domestic market shares and increases future imports.

III. Some Remarks

1. *The Multi-market competition*

The model of section II can be extended to the case where firms sell both in the home market and in the foreign market. A natural framework for the analysis is the reciprocal dumping model of Brander and Krugman (1983). In this model, each firm plays Cournot with its rival in the home and the foreign market that are mutually segmented.

Despite the increased complexity, we can show that most results in the previous section carry over. If the level of protection is modest, a temporary import protection induces the domestic firm to learn more in period 1 and enables it to expand the market shares in period 2, now both in the home and the foreign market. Note that this corresponds to the case examined by Krugman (1984), who shows that import protection promotes export in the presence of learning-by-doing. However, in our model, temporary protection can easily have the opposite results. If the level of protection is excessive, a temporary protection moves the market equilibrium from the one where the domestic firm adopts the new technology to the one where it sticks to the old technology. In this case, temporary import protection decreases future exports and increase future imports.

2. *The operation of multiple technologies*

Allowing the domestic firm to use the two technologies simultaneously change the results somewhat. Suppose the domestic firm is producing both from an old production line and from a new production line embedding a new technology. To maximize the profit, the firm allocates total production between the two lines such that the dynamic marginal cost of the new line is equated to the constant marginal cost of the old line. In this case, a temporary protection increases the total output of the domestic firm, but fails to stimulate production from the new line. The domestic firm meets the increased demand simply by producing more from the old line, keeping the dynamic marginal cost of the new line constant. Protection fails to generate additional learning.

3. *The case where both technologies are subject to learning*

We have made a polar assumption that an old technology has absolutely no scope for additional learning while a new one has a downward sloping learning curve. This assumption is not essential for the result.

Suppose that the domestic firm faces a choice between technology 1 and technology 2. Both technologies have learning curves that are downward sloping and bounded from below. At the current level of experience, the unit cost of technology 2 is higher than that of technology 1. However, the learning curve for technology 2 initially is much steeper than that for technology 1 and thus the former falls below the latter at a sufficiently high level of production. Then, we can easily have a case where the dynamic marginal cost of technology 2 is lower than that of technology 1 for low levels of production, but the reverse is true for high levels of production. This leads to exactly the same situation as depicted in figure 2.

4. *Price versus quantity competition*

The main result of this paper is not sensitive to the choice of strategy variables. To see this, suppose that the domestic firm and the foreign firm sell differentiated products and compete in prices.[10] The resulting model of Bertrand competition is different from the Cournot model in two aspects. Firstly, the best response curves have positive slopes (prices are strategic complements). Secondly, the best response curve of the foreign firm depends on which technology it expects the domestic firm to use. Given the price charged by the domestic firm, the foreign firm charges a lower price when it expects the domestic firm to use the new technology in order to discourage the learning of the domestic firm.

However, the other aspects of competition remain identical. It is easy to identify a case where the domestic firm selects the new technology only when the price charged by the foreign firm lies in a certain interval. Temporary tariff protection shifts out the best response curves of the foreign firm, increasing the equilibrium prices.[11] A sufficiently high level of tariff will push the price charged by the foreign firm out of the interval, inducing the domestic firm to select the old technology.

5. *Welfare, Information and Protection*

In this model of dynamic Cournot competition, it is very difficult to establish the general welfare effect of temporary protection. Thus, this paper does not argue that a temporary protection that induces the domestic firm to stick to the old technology is necessarily welfare-reducing.

The governments in the real world have to decide on measures of protection, with very limited information about their welfare consequences. The justification most

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[10] If the two firms sell an identical product and compete in prices, no equilibrium exists where both firms sell. However, in this case too, it can be shown that a tariff set too high may induce the domestic firm to supply the whole market using the old technology. For the analysis of learning-by-doing in a duopoly where firms engage in Bertrand competition with an identical product, see Dasgupta and Stiglitz (1988). They allow both firms to learn, but firms have no choice over technologies.

[11] The analysis of quotas in the Bertrand case is quite complicated as we have to deal with mixed strategy equilibria. See Krishna (1989) for the analysis of Bertrand competition in the presence of a VER.

often cited by those pushing for learning-inducing protection is that while consumers may have to sacrifice during the period of protection, domestic firms will become more competitive and consumers will be compensated "in the long run." The point of the paper is that these 'long-run oriented' policies may fail to deliver the desired long-run outcomes, let alone their impacts on social welfare.

General output subsidy does not solve the problem either. What is needed is subsidy targeted for a specific technology. This looks rather easy in our model, where the domestic firm has only two technologies available. However, the information requirement for the government would in general be very high when it faces a whole range of technologies to choose from. [12] Designing a truth-telling non-linear subsidy mechanism is a possibility, but it too requires detailed information on available technologies and the market structure, which is hard to come by.

V. Conclusion

This paper shows that temporary protection or delayed liberalization can *harm* the long-run competitiveness of the domestic firm. When the protected firm can choose among multiple technologies subject to different degrees of learning, the positive relationship between current production and learning commonly assumed in literature cannot be relied upon.

This result has been obtained though a highly stylized model. For example, our two-period model predicts that the firm that does not switch today never switches tomorrow. This restrictive outcome can certainly be avoided in a muti-period model. However, this paper suggests that in such a model too would remain a force by which temporary protection *delays* the adoption of new technologies.

[12] In the case of Hanbo Iron & Steel Co., whose failure precipitated the financial crisis of 1997 in Korea, people are still debating whether its new plant deserved special low-interest loans given to high-tech facilities.

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