The Declining-price Paradox of New Technologies

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The declining prices of new technology products often leads decision makers to postpone a capital investment and wait for lower prices. This paper makes a distinction between the prices of technology elements and the prices of components and systems. There are many cases where the price reduction over time applies only to some elements of the system, while the total price of the improved system remains almost the same. In these cases, a *declining-price paradox* suggests that the more the price of the investment is subject to future reduction, the more urgent it is to invest in this technology immediately. The paper presents a model incorporating learning considerations in investment decision making, and states the conditions where the paradox applies.

Key words—innovation, learning, product life cycle, DCF

INTRODUCTION

ASSUME THAT a CEO faces the decision whether or not to invest in a new computerized system. The VP for operations, supported by the VP for marketing, insists that the investment is essential to the improvement of the manufacturing facilities and will enable the company to maintain its competitive edge. However, the controller and some of the senior executives point to the declining prices of equipment of this kind. In spite of the clear contribution to productivity, they suggest waiting and procuring the system at a lower price. What should the CEO do? What tools should he use in making his decision?

Recent research has shown that traditional financial methods for investment evaluation fall short in measuring the real merit of investing in new technology (see [3–8], [11] and [12]), and in evaluating the strategic economics of new technologies (see, for example, [6]). However, it fails to take account of declining prices. Thus, in many cases, the real manager's dilemma is not *whether to buy* the new technology—often this decision has already been made— but *when* to buy it.

The declining prices of new technologies result in a tendency on the part of many decision makers to postpone the needed investment and wait for lower prices. In order to show that this passive approach is not always correct, this paper presents a step-by-step analysis, which will provide insights for decision makers.

The following assumptions are made:

- The new technology has already proved itself and is not considered 'premature' or risky; the quality of the new products is broadly recognized as being better than that of those produced by the old technology.
- Only incremental improvements in technology are expected.

The personal computer (PC) technology represents such a case (for a detailed example see [10]). There is no alternative *revolutionary* technology that might shortly replace it. Thus, many managers know that an investment in PC technology does not involve technological risks. The only question they ask is whether to buy this technology today or maybe wait a couple of months to obtain better prices or improved performance.

Model No. 1: the traditional discounted cash flow (DCF) approach

The simple classical approach examines the myopic dilemma whether to buy the system today or tomorrow. If we buy the system today, the price is A; if we buy it 'tomorrow' the discounted price will be B, and the natural assumption is that $B < A$. On the other hand, there are benefits to be gained from applying the new technology. If we apply the system today, the net present value (NPV) of the benefits will be X; tomorrow, they will be Y, and X is assumed to be greater than Y.

The decision criteria according to the discounted cash flow (DCF) evaluation are as follows:

If $X - A > Y - B, 0$, buy today.
If $0 > X - A > Y - B$, do not invest.
If $X - A < Y - B < 0$, do not invest.
If $X - A < Y - B > 0$, buy tomorrow.

This DCF approach ignores both the impact of the time needed to learn any new technology and the behavior of the competitors. Temporary noteworthy declines in productivity often accompany the introduction of new process technology [7], and if we apply the new technology too late we may lose our competitive edge.

Example 1 in the Appendix gives a numerical illustration of this approach.

Learning-curve considerations

We will now incorporate learning-curve considerations into the decision-making process. Thus, even if calculations of the net present value suggest a postponement of the investment, by permitting managers and workers to gain experience with the technology, investing today can still be valuable. The problem may therefore be presented as having the following alternatives:

- Wait for the price of the new technology to decline or
- Invest now, at today's prices, and gain learning experience. In learning curve models, experience of a process or technology decreases the process time and the cost (see, for example, [1], [2] and [9]).

While most of the literature deals with the learning benefits to the *producer* of a product or a service, we focus on the *user's* learning process.

It is common to assume a logarithmic relationship [13] between the production cost (or time) of a unit and the number of units produced (or time of use of the new system) according to

$$Y_x = KX^n \tag{1}$$

where

x = unit number
Y_x = number of hours (cost) required to produce the xth unit
K = number of direct labor hours (cost) required to produce the first unit
n = learning constant.

The traditional model (Model No. 1), using the number of units (x) as the independent variable, is modified (Model No. 2), and the *time* of learning is taken as x.

Figure 1 shows the learning curve of these two options. Assume that Firm I invests 'today' (at time t_0) while Firm II decides to wait for better prices and invests at time t_1. The model assumes stationary learning slopes. At any given time, t^* ($t^* > t_1$), Firm I has a definite advantage over Firm II. We shall denote $T = t_1 - t_0$, and $T^* = t^* - t_1$.

The experience advantage of Firm I is represented by the shaded area—designated $L(t^*, t_1)$—and may be calculated as follows:

$$\begin{aligned} L(t^*, t_1) &= KT + \int_{t_1}^{t^*} K(t - t_1)^n \,\mathrm{d}t - \int_{t_0}^{t^*} Kt^n \,\mathrm{d}t \\ &= KT + \{K/(n+1)\}\{T^{*n+1} - t^{*n+1} + t_0^{n+1}\} \end{aligned} \tag{2}$$

Let us assume that the prices are declining according to

$$B(t_1) = Ab^T \tag{3}$$

where b is the decline in price per period, $0 < b < 1$.

Incorporating equations (2) and (3) into the traditional DCF evaluation modifies our decision rules:

Invest today if

$$X - A + L(t^*, t_1) > Y(t_1) - Ab^T > 0 \tag{4}$$

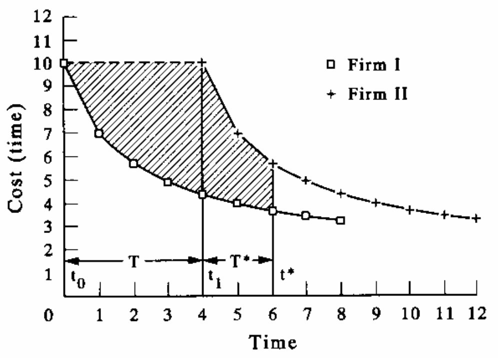

Fig. 1. Learning considerations.

Buy tomorrow if

$$X - A + L(t^*, t_1) < Y(t_1) - Ab^T > 0 \tag{5}$$

Do not invest if

$$X - A + L(t^*, t_1), \quad Y(t_1) - Ab^T < 0 \tag{6}$$

Example 2 in the Appendix shows that a decision may be changed after incorporating learning considerations.

If equation (4) or (5) is positive, a given t^*, we can maximize the NPV. Optimization yields the best timing (t_1) for the investment:

$$\max_{t_1} \{L(t^*, t_1) + Ab^T\} \tag{7}$$

Example 2 demonstrates this optimization.

Figure 2 is a plot of the cost reduction versus gain in learning. At some time in the future, t^*, we measure the benefits of the new technology. If the measurement takes place at an early stage ($t^* \rightarrow t_1$) the learning benefits become higher and may dominate the decision. This may be the case of products having a short life cycle.

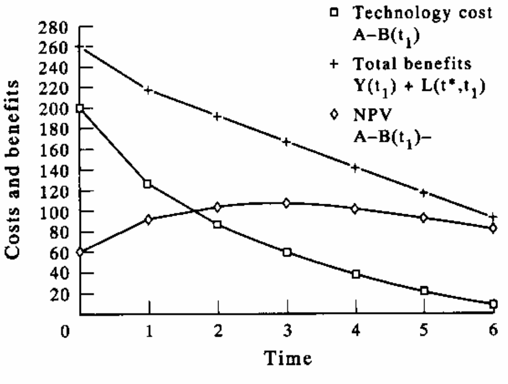

Fig. 2. Cost reduction vs learning gain.

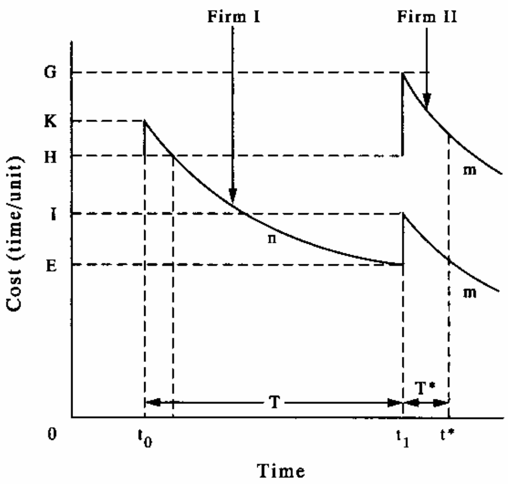

Fig. 3. The 'pay twice' model.

A further modification, Model No. 3, deals with the 'pay twice' problem: is it worthwhile to wait for the newer technology, or buy the technology now and thus 'pay twice' when the newer technology becomes available?

Let us consider two companies operating in the same environment:

- Firm I bought a system some time ago, and paid the high price (A) of the new technology.
- Firm II is going to buy a system today. This system is a better one, and has a better performance. Firm I is willing to upgrade its system, or to buy a new one (at an incremental cost of A_1) in order to keep abreast. No doubt the time required for Firm I to master the new technology will be much shorter than that for Firm II. The learning experience plays an essential part in these decisions.

These learning benefits, are quantified in Model No. 3 by modifying the basic learning-curve model to assess the value of introducing new technologies (see [13]). Figure 3 illustrates Model No. 3. At time 0, both firms hold the same production time and performance H. At time t_0 Firm I buys the new technology. It has a temporary decline in productivity and produces the first product at cost K. The difference $H - K$ represents the temporary decline in productivity. By time t_1, Firm II decides to invest in the modern technology. Firm I, optimizing its NPV, upgrades its system, and has thus apparently paid 'twice' for the system. Firm II's cost has increased by $G - H$, reflecting the adoption of a complex technology. Note that $G - H > K - H$, reflecting the fact that the new system is more complex than the old one. However, Firm I's conversion cost is only $I - E < G - H$. The fact that the new system is more productive is demonstrated by the steeper slopes of the new learning curves.

The improved productivity of the new system is a result of the advanced technology as well as certain externalities.

Though Firm I has apparently paid 'twice' for its technology (at points t_0 and t_1), the purchase at time t_0 puts Firm I in the position to make the move at time t_1 with less effect on productivity than for Firm II.

We assume that the new technology learning curve slope $m (m > n)$ will be the same for the two firms, though Firm I starts from a lower point. To determine the operational benefit, we can calculate the area between the two learning curves, which represents the extra benefits to Firm I. Thus, for any $t^* > t_1$ the gain in learning (L) is

$$\begin{aligned} L(t^*, t_1) &= H(T) + \int_{t_2}^{t^*} G(t - t_1)^m \,\mathrm{d}t \\ &\quad - \int_{t_0}^{t_1} K(t - t_0)^n \,\mathrm{d}t - \int_{t_2}^{t^*} I(t - t_1)^m \,\mathrm{d}t \\ &= H(T) + GT^{*m+1}/(m+1) \\ &\quad - KT^{n+1}/(n+1) - IT^{*m+1}/(m+1) \\ &= HT + (G - I)T^{*m+1}/(m+1) \\ &\quad - KT^{n+1}/(n+1). \end{aligned} \tag{8}$$

Modifying equation (7) to find the optimal time to invest in the new technology, yields

$$\max_{t_1} \{L(t^*, t_1) - A_1(t_1) + Ab^T\} \tag{9}$$

where $A_1(t_1)$ is the upgrading cost at time t_1.

The declining-price paradox of new technologies

The declining-price paradox states:

Under the paradox conditions, the more the price of the investment is subject to future reduction, the greater the urgency to invest in the technology as early as possible.

This apparent paradox is explained by the following arguments: The greater the price reduction expected, the more complex future systems are going to be. This will result in more learning time (i.e. more operating expenses). The mechanism is explained in this section.

In a systematic approach to explain this paradox, we use the following terms:

- The total system to be implemented will be called the *system.*
- The system consists of several *components.*
- The components are built of *elements.*

Let us refer to the PC example: the total PC system is the *system.* It consists of a PC (monitor, keyboard and CPU unit), a printer and a modem, each of them being a *component.* Each component consists of *elements,* the PC component elements, for example, are memory chips, floppy or hard disk, etc. The declining-price paradox is valid under the following conditions:

1. Prices of the technological elements are in decline. Thus, the prices of components having the same elements are in decline. If you buy the *same* system some time in the future, you will pay much less than today.
2. Tomorrow's *systems* will be more complicated than today's systems. They will include more elements and components, and the learning time will be longer. For example, the IBM PC, introduced in 1981, had two floppy disk drives. In the next generation one of the floppy disks was replaced by a hard disk, an *element* much more complex to learn.
3. Substantial learning time is needed to master the new technology.
4. The price of the *system* remains almost the same, but performance is improved.
5. The product's cost per unit declines using the new technology. Under these five conditions, the higher the price reduction expected, the greater will be the future learning costs ($G - H$ in Fig. 2). This will bias the decision such that t_2 is moved back toward t_0.

The competition forces companies and individuals to buy state-of-the-art technology. The

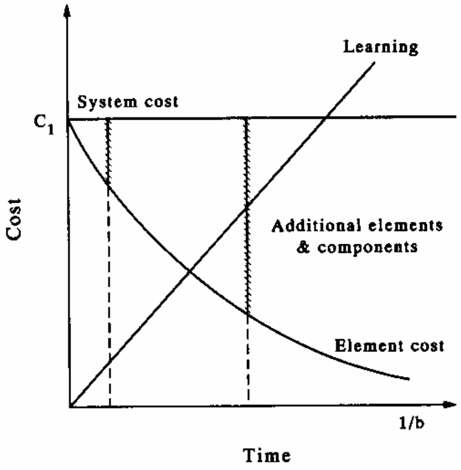

Fig. 4. The declining element cost and the increasing learning cost.

decline in price of the *elements* does not necessarily mean a decline in the prices of components or systems. In many cases, the component price remains the same, while yielding many more options and better performance: the *systems* have more components than before, and more complex functions. The result is that the learning time increases.

Figure 4, presents the expected reduction in element cost (Condition No. 1). The system cost remains constant (Condition No. 3). Thus (Condition No. 2) the cost of learning may increase because of the necessity to master the additional components added to the system. The shape of the extra learning curve will apparently be convex since more functions are added to the system. However, the trend in software and hardware development toward more friendly software may transform the convex function into a more linear one.

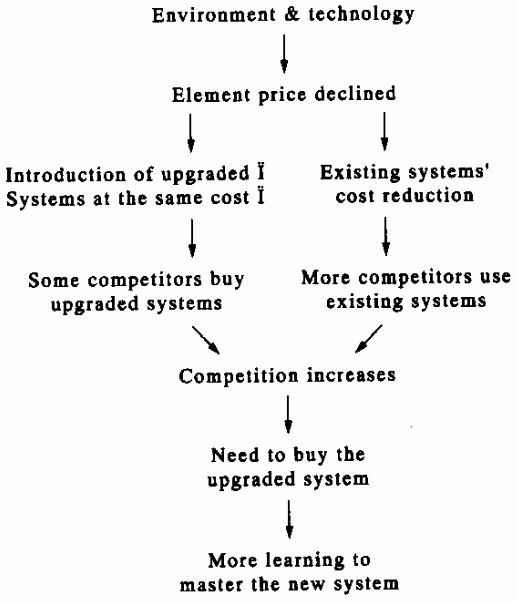

Fig. 5. The declining-price paradox.

Some empirical indications may be cited to support this argument [10]. Lotus 123 by Lotus Development has the same friendly interface in both release 1A and 2.01. The package list price for the two releases remains the same ($495) while the number of options has almost doubled, resulting in more learning time. The same trend is identified in other PC software and hardware (e.g. Disk Operating System, dBASE package etc.).

Thus, the more the element prices are subject to future decline (the right-hand side of the horizontal axis in Fig. 4), the earlier the system should be purchased.

Figure 5 shows the mechanism that affects the declining technology price paradox: the technology and other external forces result in element price decline. This price decline has two implications:

- Prices of the existing systems decline.
- Introduction of improved systems.

These implications result in increased competition, and a company that uses the old technology exposes itself to a strategic threat. Sooner or later the firm will invest in the new system, and will spend more time on learning.

CONCLUSIONS

The points to be emphasized may be summarized as follows:

- The learning time should always be taken into consideration whenever examining an investment in a new technology.
- Buying today's technology may provide an advantage whenever an organization goes on to a new generation of technology, by reducing learning time and enabling earlier use of the new technology.

- The technology price reduction is sometimes a mirage in terms of both tactical and strategic considerations. The price reduction affects *elements*, and not *systems*. As the price of elements declines, systems tend to become more complex though their prices tend not to decrease.

APPENDIX

Example 1

A company is willing to buy CAD/CAM (computer aided design/computer aided manufacturing) equipment.

> The initial cost now is A = $200,000. The declining price rate is 25% per year.
>
> The machine can produce the product at a cost of $1.00 per unit, while the sale price is $1.50. The quantity expected to be produced and sold is 120,000 units per year, for the next 6 years.

Without this equipment, the product can be produced at a cost of $1.30. The cash flow (with and without the investment) and the net present value (at a cost of capital of 10%) will be as follows:

Year of investment	Cash flow 0	1	2	3	4	5	6	NPV
0	(200)	60	60	60	60	60	60	61
1	0	(126)	60	60	60	60	60	92
2	0	24	(88)	60	60	60	60	105
3	0	24	24	(60)	60	60	60	108
4	0	24	24	24	(39)	60	60	103
5	0	24	24	24	24	(23)	60	95
6	0	24	24	24	24	24	(11)	84

Thus, according to the traditional DCF approach, the decision will be—do not invest now. The optimal time for investment is in year 3, where we maximize the NPV.

Example 2

This example demonstrates the learning effects described in Model No. 2. Let us refer to Example 1 and assume that each year the learning curve is 70%.

The marginal cost to produce a unit at the nth year will be

Year	Cost
0	1.000
1	0.700
2	0.568
3	0.490
4	0.437
5	0.398
6	0.367
7	0.343
8	0.323

Learning considerations are now incorporated to yield cash flow and NPV. The cash flow is calculated by taking into consideration that the cost per unit produced is variable, as shown in the table above. Instead of $1.00 every year, the cost is reduced (due to learning effects) to $0.700 in the first year, etc. Thus

Year of investment	Cash flow 0	1	2	3	4	5	6	NPV
0	(200)	96	111	121	127	132	135	316
1	0	(126)	96	111	121	127	132	285
2	0	24	(88)	96	111	121	127	244
3	0	24	24	(60)	96	111	121	199
4	0	24	24	24	(39)	96	111	155
5	0	24	24	24	24	(23)	96	115
6	0	24	24	24	24	24	(11)	84

The annual profit using the old technology is $24,000. The cost of the equipment if invested in year 0 is $200,000. This cost is reduced by 25% each year. In the year the investment is made, the operating profit is still $24,000 (minus the investment). The expected $60,000 profit grows on account of the learning experience to $96,000 the next year, to $111,000 the year after and so on. The optimal decision here is to invest now (year 0) and maximize the NPV.

If we ignore the learning phenomenon, and wish to maximize NPV, we will reach a different decision (invest in year 3). Figure A1 shows the different NPV structures under the two assumptions (with and without learning considerations).

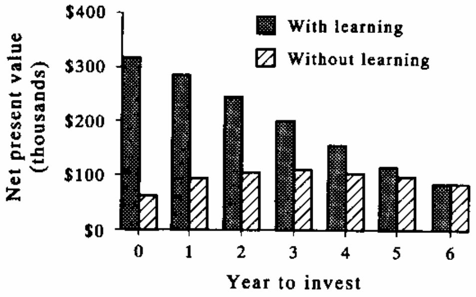

Fig. A1. NPV vs investment timing with and without learning.

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