Technological Change and Industrial Innovation

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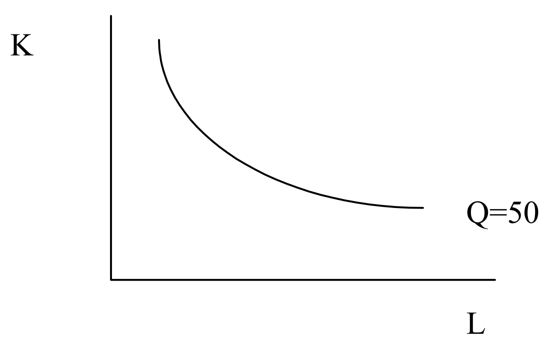
Introduction

Technological advancement allows a company to get more output out of the same amount of inputs—that is, it allows the firm to use its capital and/or labor more productively. Innovation reduces average production costs. This reduction may allow the firm to increase its profit level, to lower its prices, or to merely survive in a competitive environment where all firms are innovating. Innovate or die! Don't be like the little man in Alan Jackson's song, whose business dies due to a failure of innovation. We'll explore this fascinating world in the pages to come.

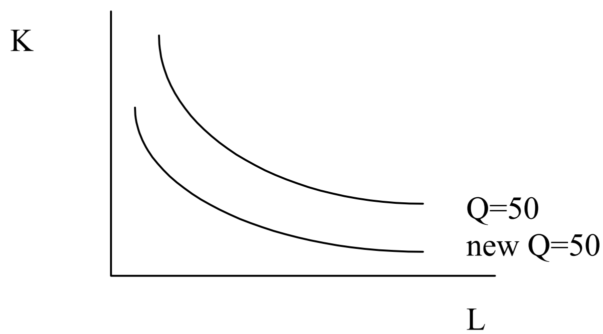
First, let's represent the results of innovation using the models of production that we have developed earlier in the semester.

Technological Advancement and Isoquants

Recall that an isoquant represents all of the combinations of two inputs that are capable of producing the same amount of output. For example, here is an isoquant representing the combinations of capital and labor that can produce 50 units of pork rinds.



Now suppose that a technological innovation allows the firm to get the same amount of pork rinds using less capital and labor. The new isoquant for Q = 50 would be closer to the origin:

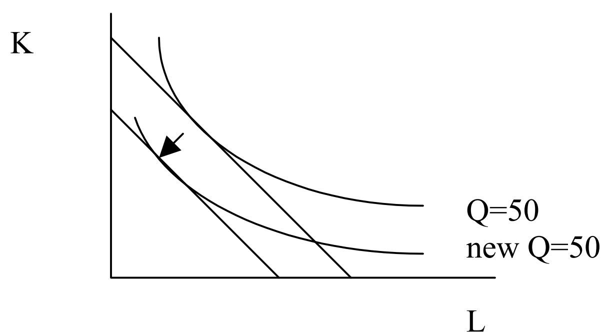


Perhaps you can see the cost advantages to innovation. It allows the firm to either

(a) produce the same amount of stuff for a reduced total cost or

(b) produce more stuff with the same amount of dollars that they were producing less stuff before the innovation.

Here is (a) graphed:



Technological Advancement and Production Functions

Consider this linear production function:

$$Q = A(BK + CL)$$

example: $Q = 10(3K + 4L)$

How will innovation affect this production function? Depends on what kind of innovation it is. There are three possibilities:

1. The innovation increases the productivity of both capital and labor.
   In this case, the "A" term in the production function would get bigger. Using the example from above, the production function might change
   from $Q = 10(3K + 4L)$ to $Q = 12(3K + 4L)$

2. The innovation increases the productivity of capital but not labor.
   In this case, the "B" term in the production function would get bigger. Using the example from above, the production function might change
   from $Q = 10(3K + 4L)$ to $Q = 10(4K + 4L)$

3. The innovation increases the productivity of labor and not capital.
   In this case, the "C" term in the production function would get bigger. Using the example from above, the production function might change
   from $Q = 10(3K + 4L)$ to $Q = 10(3K + 5L)$

Now that we've taken a general view of technological change and innovation, let's take a more specific look at some issues. (By the way, the text makes some subtle distinctions between terms such as *technological change*, *invention*, and *innovation*. These distinctions are not from the general science of economics, and we shall ignore them here.)

Research and development

A firm must spend money on research and development if it hopes to innovate. But there are several concerns, if one is doing research to attain some specific objective (say, developing a blue laser):

--the amount of R&D spending required to achieve the objective is uncertain.
--success is uncertain.

So how can a company gauge the best level of R&D spending? Well, it can try to estimate the how much money the R&D will cost under different scenarios, and the likelihood that such spending will have success. Let's digress for a bit and discuss *probability*.

Digression: Probability and expected value

Probability

The *probability* that something will occur (in the future) is expressed as a number, which can range in value from 0 to 1. If an event has a probability of 0 then it will not occur under any circumstance. If an event has a probability of 1 then it will definitely occur under all circumstances.

Most future possible outcomes have a probability lying between 0 and 1. For example, the probability that when you flip a coin it will come up "heads" is ½, or .50. Another example: The probability of blindly drawing a queen out of a deck of cards is 4/52, or .076923.

Probability of two things happening together:
The probability that two things will happen together equals the probability that the first thing will occur multiplied by the probability that the second thing will occur. Example: If you toss a coin twice, the probability that it will land "heads" both times = .50 x .50 = .25. Another example: The probability of rain today is 20% and the probability of rain tomorrow is 30%; the probability that it will rain both today and tomorrow = .20 x .30 = .06

Expected value

Expected value means average. An expected value is a weighted average of all possible outcomes of an action, where each outcome is weighed according to the probability that it will occur.

Example: You are on a game show. You blindly draw a card from a deck. If it is the ace of spades then you win $1000; if it is any other card then you win $10. The expected value of your draw is:

expected value = (1/52)($1000) + (51/52)($10) = $19.23 + $9.81 = $29.04

Here's an application of probability and expected value to a highly-simplified R&D action:
Scientist Jimmy has a plan to produce a blue laser. He believes that there is a 20% probability that he can produce the laser at a cost of $60 million, and an 80% probability that he can produce the laser at a cost of $125 million.[1] The expected value of Jimmy's R&D is

expected value = .20(60,000,000) + .80(125,000,000) = $112,000,000

[1] Dollar amounts include opportunity cost and are discounted to their present value. (More about present value in another set of notes.)

End of probability and expected value digression

<u>Issue 1: R&D and parallel development efforts</u>

Given that an individual R&D effort has no guarantee of success, it is often a superior strategy to undertake parallel development efforts in an attempt to obtain a specific innovation. Let us do a highly simplified example. Suppose we know the following three things:

1. Scientist Fujia has a plan to produce a blue laser. He knows that there is a 50% probability that he can produce the laser at a cost of $100 million, and a 50% probability that he can produce the laser in at a cost of $125 million. (There is no chance of failure under this plan; in the worst case it will cost $125 million.)

2. Scientist Gomez-Wilkinson also has a plan to build a blue laser. She believes that there is a 50% probability that she can produce the laser at a cost of $90 million, and a 50% probability that she can produce the laser at a cost of $130 million. (There is no chance of failure under this plan; in the worst case it will cost $130 million.)

3. If both plans are pursued simultaneously, then after a period of time, the firm can figure out the true cost of each plan; then it can go with the plan that is cheaper and it can drop the other plan. (Let's say that this occurs after having spent $C on the dropped plan.)

What should the firm do? They have three options:
OPTION (1): go with Fujia's plan and ignore Gomez-Wilkinson's
OPTION (2): go with Gomez-Wilkinson's plan and ignore Fujia's
OPTION (3) go with both plans for a time then dump one of them, having spent a total of C dollars on the dropped plan.

Let's examine each of these options:

OPTION (1) <u>Go with Fujia's plan</u>: the expected value of the cost of this choice is
expected value = .50(100,000,000) + .50(125,000,000) = $112,500,000

OPTION (2) <u>Go with Gomez-Wilkinson's plan</u>: the expected value of the cost of this choice
expected value = .50(90,000,000) + .50(130,000,000) = $110,000,000

<u>Go with OPTION (3):</u>
There are four possible outcomes to this option, each equally likely:

(i) After spending $C on Fujia's plan, it is abandoned because it will cost $100 million. Gomez-Wilkinson's plan is continued, and the Gomez-Wilkinson plan costs $90 million.

(ii) After spending $C on Fujia's plan, it is abandoned because it will cost $125 million. Gomez-Wilkinson's plan is continued, and the Gomez-Wilkinson plan costs $90 million.

(iii) After spending \$C on Gomez-Wilkinson's plan, it is abandoned because it will cost \$130 million. Fujia's plan is continued, and the Fujia plan costs \$100 million.

(iv) After spending \$C on Gomez-Wilkinson's plan, it is abandoned because it will cost \$130 million. Fujia's plan is continued, and the Fujia plan costs \$125 million.

Each outcome (i)-(iv) has a 1/4 probability of occurring[2]. So the expected value of the cost of OPTION (3) is:

Expected value = .25(C + 90,000,000) + .25(C + 90,000,000) + .25(C + 100,000,000) + .25(C + 125,000,000)

= .25C + 22,500,000 + .25C + 22,500,000 + .25C + 25,000,000 + .25C + 31,250,000

= \$C + \$101,250,000

Analysis of options (1), (2), and (3):
Compare the expected values of the costs of options (1), (2), and (3), which I rewrite here:

expected value of cost of OPTION (1): \$112,500,000
expected value of cost of OPTION (2): \$110,000,000
expected value of cost of OPTION (3): \$C + \$101,250,000

If \$C is less than \$110,000,000 - \$101,250,000, then option (3) has the lowest expected value of the 3 options. That is, if the firm can determine which plan is cheaper before either Fujia or Gomez-Wilkinson has spent \$8,750,000, then the firm should go ahead with option (3)--parallel development efforts.

Issue 2: Time vs. cost

Trying to cram a given R&D project into a shorter time period has its benefits and its costs. First, the shorter time period lets you get a bigger jump on the competition, and this probably augments revenues. Second, costs will be higher as one tries to rush through an R&D project.

One must consider these tradeoffs when deciding on the duration of an R&D project. Here is a highly simplified example[3]:

Flapping Wand Inc. will undertake an R&D project to improve its flapping wands. As a result, it expects to augment its revenues according to this function:

$R = 500 – 10t$ where "t" represents the number of months required to complete the project

[2] The probability of two events occurring together, recall, is the probability that one will occur multiplied by the probability that the other will occur. In each of cases (i)-(iv), the probability = .50 x .50 = .25
[3] All dollar values include opportunity cost and are discounted to present value.

The total cost of the R&D project is expected to be:

$C = 600 - 50t + 2t^2$

Question: How many months should it take on the R&D project?

Answer: First, let's combine the two equations into a profit equation. Recall that total profit, π, equals total revenue minus total cost:

$\pi = TR - C$

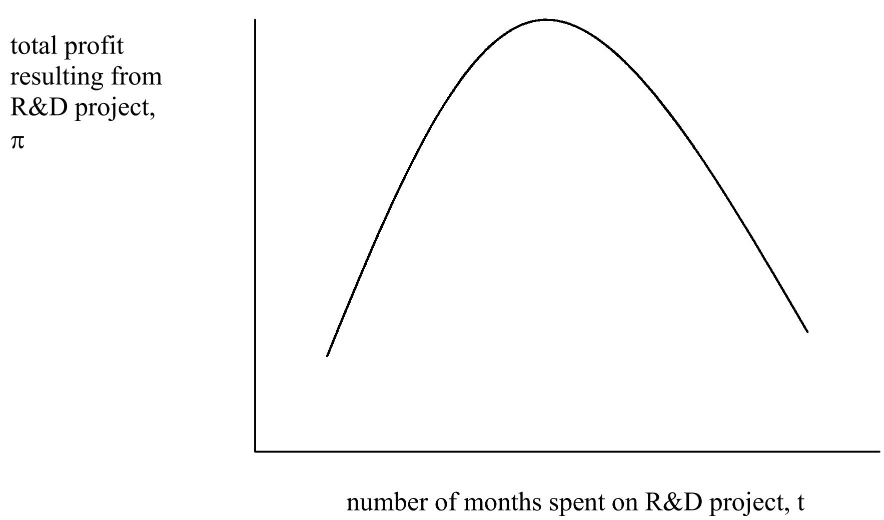
Substitute Flapping Wand's revenue and cost equations for their R&D program into the profit equation:

$\pi = (500 - 10t) - (600 - 50t + 2t^2)$

$\pi = 500 - 10t - 600 + 50t - 2t^2$

$\pi = -100 + 40t - 2t^2$

Notice that profit depends upon t. If we graphed the profit equation we would get an arc looking like this, sort of:



We want to locate the peak of this curve—the number of months that will maximize the profits made possible from the R&D. How do we locate this peak? Using derivatives!!!!! Egad.

Recall that the derivative $d\pi/dt$ measures the change in profits that occur when t is increased a little bit. It is represented by the slope of a line tangent to a point on the profit arc. Well, at the peak of the arc, the slope of a line tangent to the arc is zero. So if we find the value for t at which $d\pi/dt$ is zero, then we have found the peak! The profit-maximizing t! How much joy can you take!!!

Let's re-write our profit equation:

$\pi = -100 + 40t - 2t^2$

Now let's take the derivative of the profit equation with respect to t:

$d\pi/dt = 40 - 4t$

Now let's set the derivative equal to zero and solve for t:

$40 - 4t = 0$

$4t = 40$

$t = 10$

So the profit-maximizing number of months to do the R&D is 10.

Issue 3: The Learning Curve

Consider Dell computer. They continue to produce higher quality computers at a lower per unit cost. How? In part it's because of learning by doing; as their engineers and assembly workers produce more and more product over the years, they learn how to reduce the average cost of producing a computer. This is known as the learning curve effect:

The *learning curve effect* stipulates that learning causes the average cost of producing a product to fall as the firm's cumulative total number of units produced rises over time.

Firm planners should factor gains from the learning curve effect into their cost calculations. Note, however, that it may be more difficult for a mature firm to derive gains from this effect than a younger firm, since the mature firm may have already found most of the large gains from learning, leaving fewer gains open to it.

Oh, we have learned lots about technological change and innovation. What fun!