Lecture 6

Technological Change and Productivity Readings-Surveys

In this chapter we will briefly review issues on

1. Generation and Nature of Technological Change
2. Diffusion of Technological Change.
3. Market Structure and R&D and Technological Activity (Stiglitz, Kamien).
4. Social Evaluation of R&D Activities (Griliches, Schmitz)
5. Measurement of Technological Change (Griliches, Denison, Farrell).

6.1 Nature of Technological Change and R&D

The first question we need to ask is: What is technological change and how is it measured? In short, technological change reflects the ability to get more output from the same amount of inputs. It can be reflected by:

1. an increase in an index of quantity of output per unit of input, or
2. a change in production function parameter.

The first controversy we encounter in the economic literature on t.c. concerns how one accounts for changes in input use when measuring technological change. Here we have two schools of thought:

Heady and Denison

Heady and Denison claim that technological change accounts for all the growth in output that is not accounted by growth in *physical* input use. They measure an exogenous shift of isoquants where input measures are unchanged. They include changes in *quality* of input as part of technological change and measure use of input in each single period.

Schultz-Jorgenson and Griliches

Schultz-Jorgenson and Griliches claim that technological change reflects changes in production functions that cannot he explained otherwise. Specifically, technological change reflects changes that cannot be explained in terms of increased quality and/or quantity of inputs. Technological changes are measured in input–output ratios when quality changes are taken into account.

The Schultz approach enlightens two manifestations of technological change.

1. Increase in *knowledge* of the production process
2. Improvement in input quality

Accordingly, **Peterson and Hayami** define technological change as

> "the phenomena of input quality improvements for an increase in knowledge leading to increase in output per unit of input."

This definition tries to generate a compromise in the embodied–disembodied controversy. For years, economists have asked: Do technological changes embody themselves in new machinery or are they slow processes of change in production techniques? Again, do technological changes arise from better input or better management?

The disembodied hypothesis relied on evidence from the an airplane industry when time required to assemble a plane declined with the increase of number of planes produced. People developed the notion of a "learning curve" where output/labor = f(time) or output/labor = f(output); f is found to be logarithmic. Arrow developed accordingly this theory of "learning by doing" in 1961.

The book by Salter (1960) is a cornerstone of an alternative approach that embodies hypotheses and the "Putty Clay" approach. Here, as we have seen in a previous chapter, it is assumed that there is a choice of input–output coefficients before a new technology is introduced and, once an investment takes place, an input/output ratio is fixed. In other words, before the new machinery is introduced, you are in putty stage; after you adopt, you have clay and the input/output ratio is virtually constant.

The new technology is considered embodied in the machinery that need to be bought. Technological change reflects itself in the putty stage every year the possibilities in terms of machinery are better. Note however that these two theories –embodied vs. disembodied– are more complementary than contradictory. It is true that new machinery, embodying new knowledge, is introduced constantly, but use efficiency improves with experience, as the user acquires new managerial ability.

A second important issue relates to the direction or technological change. With technological change, is the neoclassical production function (the *ex ante* one, la Salter) changing in a neutral or a biased manner? Technological change can he described as a shift of the unitary isoquant toward the origin (one unit of output can be produced with less inputs), but the shift can be "parallel" (that is, the quantity of all inputs declines proportionally to their use) but can also be biased (some inputs reduce more than other).

There are three measures of technological bias. All three measure what occurs to the ratio $F_K K/F_L L$ along a certain line and can be interpreted as measures or what happens to the (share of capital)/(share of labor) over time along that particular line:

1. **Hicks** measures bias along the fixed capital/labor ratio
2. **Harrod** measures bias along fixed capital/output ratio
3. **Solow** measures bias along fixed labor/output ratio.

Figure 6.1: Hicks' measure of technological bias

$$\left.\frac{\partial\left(\frac{F_K K}{F_L L}\right)}{\partial t}\right|_{\text{given } \frac{K}{L}} \gtreqless 0 \Rightarrow \begin{cases} \text{labor-saving} \\ \text{neutral} \\ \text{capital saving} \end{cases}$$

Given these definitions, the question is: What is the nature of technological change in the real world?

According to Salter, technological changes are neutral. He agrees that observed data indicate that capital/labor ratio is increasing over time, but he explains it as the consequence of the increase in the relative price of labor (the economy is moving along the isoqants towards a more intensive use of capital, but the shape of the isoquants remains unchanged).

He states that manufacturers want to minimize cost and do not care if this is due to labor or capital saving. Therefore, they will encourage research possibilities that reduce both capital and labor requirements.

Figure 6.2: This change, from Q_0 to Q_1, is capital saving

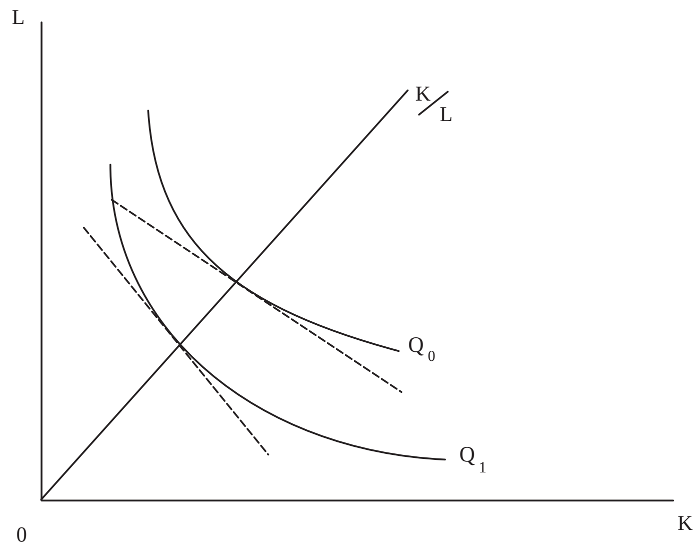


Figure 6.3: This change, from Q_0 to Q_1, is labor saving

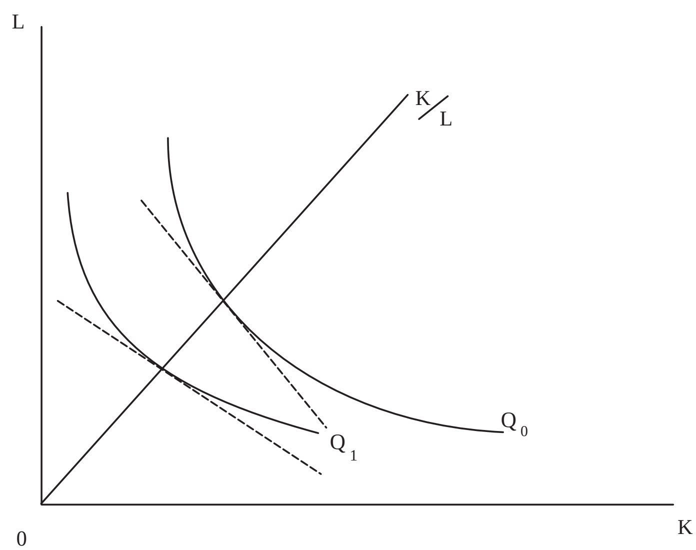
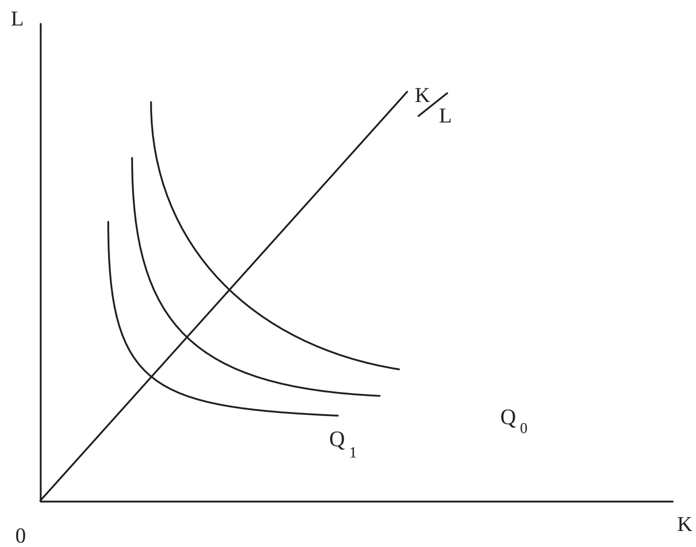


Figure 6.4: Stiglitz and Atkinson technological change



His approach is opposed by an alternative approach, the **induced innovation approach**, which mantains that research and innovation efforts that shift production functions are affected by relative prices.

Hayami and Ruttan applied this approach to show that differences in endowment determine differences in relative prices which affect the direction of R&D in different countries. **Binswanger** extended their work and developed an empirical model for understanding technological bias.

Stiglitz and Atkinson have a theory following Joan Robinson's ideas. Given an initial isoquant, an initial technology, the R&D activity is close to this technology and the *ex ante* production function becomes less and less elastic and sensitive as prices changes. Thus, even in the ex ante production function we may find regions of extreme rigidity. The result will be that a country might be very efficient along one K/L ratio, but very undeveloped along another.

6.1.1 Binswanger Model

Before we introduce this model, note that it is agreed that technological change includes many processes but two are important: (1) innovation and (2) diffusion. Both processes are processes of investment –innovation is an investment in R&D

and diffusion is an investment in capital, education, etc. Here we analyze the determination of the direction of an innovative effort. It is assumed that the innovator is the user of the new technology –an unlikely assumption in agriculture, where there is a separation between a developer of new technology and its user. However, it is reasonable in other industries, where a firm develops, in part or totally, its technologies. This model is also relevant for a competitive economy where all industries are competitive and one is gaining all the benefits he creates.

The model is based on the **Evanson and Kislev** model of applied research. It assumes that this is the research that firms will be concentrating on. Research is a search for new products, input processes, etc. It is a random drawing from a density function. Basic research defines the density –probability of success– and applied research is actually using the probability rule and searching. They dealt with the investigation and search of a new high yield variety, number of experiments in N if Y_i is a well-behaved r.v. Then $Y(n) = \max_{i=1,\dots,N}\{Y_i\}$ is a new r.v. with

$$\frac{\partial E[Y(N)]}{\partial N} > 0, \qquad \frac{\partial^2 E[Y(N)]}{\partial N^2} < 0.$$

Binswanger assumes that R&D activities can be modeled using a similar framework. The output of R&D activities are parameters of production function and, as the R&D effort increases, one may expect to see technologies with lower input-output ratios.

Let us assume that the firm's production function is $Y = f(K/A, L/B)$. A and B are measures of capital and labor productivity and, as they decline, productivity increase.

Now assume that you start with initial parameters, A_0 and B_0, and start R&D efforts to develop new technology. The measure of success is

$$A^* = \frac{A_0 - A_1}{A_0}, \qquad B^* = \frac{B_0 - B_1}{B_0}$$

Suppose there are two research lines, M and N; M is capital saving and N is labor saving. Let

N = number of research units under N;
M = number of research unit under M;
α^N = productivity of one unit of successful research type N in capital saving;
α^M = productivity of one unit of successful research M in capital saving; and
β^N and β^M = measure of labor saving productivity.

Expected success is measured by $u(\cdot)$ where $u' > 0$ and $u'' < 0$. Two research lines are complement if

$$\alpha^N > \beta^N > 0 \qquad \alpha^N > \beta^N > 0.$$

They are substibtes if

$$\alpha^N > 0\beta^N \qquad \beta^N > 0 > \alpha^N.$$

The total expected effect of R&D are

$$A^* = u(N)\alpha^N + u(M)\alpha^M = A^*(M,N),$$

$$B^* = u(M)\beta^M + u(N)\beta^N = B^*(M,N),$$

Assume that $Y = min(L/B, K/A) - Y$ is given and assume that P_L and P_K are given. Then risk-neutral firms,

$$\max PY - P_K K_0 - P_L L_0 + P_K K_0 A^*(M,N) + P_L L_0 B^*(M,N) - MP_M - NP_N = V + C_K A^*(M,N) + C_L B$$

where $C_K = P_K K_0$, initial cost of capital $C_L = P_L L_0$, initial cost of labor

The model determines M and N and that determines the technological bias. Let us define it by

$$\text{bias} = u(M)(\alpha^M - \beta^M) + u(N)(\alpha^N - \beta^N).$$

Binswanger found that bias and research scale depend on

- Price of research line
- Productivity of research line
- Initial cost of each factor
- Output level

More details:

1. Research productivity depends on: Relative productivity of research line; if capital–intensive research yields quicker results, it will be used.
2. Output– More output will yield more research.
3. Input cost.

In terms of labor and capital, high wages and interest rates will affect labor–saving or capital–saving efforts

Criticism

1. *Theoretical grounds*: It is too limited.

   (a) Production function is fixed proportion –no C.E.S.

   (b) Ignores risk and risk aversion.

   $$\max EU\left[PF\left(\frac{K}{A},\frac{L}{B}\right)-wL-rK-MP_M-NP_N\right]$$

   subject to

   $$A=A_0[1-A^*(N,M)]$$
   $$B=B^*[l-B^*(N,M)]$$

   (c) Ignore dynamic aspects of R&D.

2. *Realism*

   (a) Ignore market structure.
   In agriculture the farm input sector is independent from the farming sector. The input producers are monopolists or oligopolists and use their power in determining quantity and quality research. The input producer has to take into account the realities of the adoption process in their decision making, and R&D decisions depend on adoption procedure parameters and are also determined simultaneously with promotion choices.

   (b) This R&D process is limited to biological and chemical technological changes. In mechanical changes there is a specific dynamic aspect that is ignored. The research process can be then described by an optimal control model.

Generally, modeling R&D is not only important for agricultural problems –it is also essential for energy and resources. There are many new models that relate to optimal search procedures for oil– for new organic sources of energy, etc. –that have some of the elements of the Binswanger model but use also dynamic arguments.

6.2 Adoption diffusion

Technological change is a multistage process, Schmookler distinguished between:

1. the process of innovation, and

2. the process of adoption and diffusion.

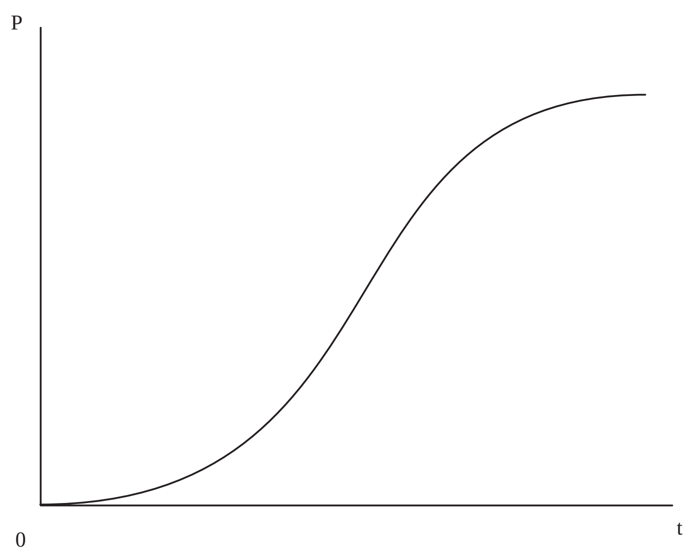
Both processes require some investment and sacrifice; in some industries they are taken separately by different firms and in some they are taken within the same firms.

6.2.1 The adoption of new technology

It is naive to think that once a new technology is introduced it is adopted immediately. The process of adoption is time consuming; it took about 40 years for a complete adoption of the mechanical tractor and about three to five years to complete the adoption of the tomato harvester. Other types of technological adoption –the "right" use of fertilizers and the use of new varieties– also take time and follow interesting patterns.

The study of diffusion processes has concentrated on two areas: diffusion of durable goods (such as television sets) and diffusion of high yield varieties (HYV) by farmers. **Bain and Griliches** studied the diffusion rate (percent of adopters of total population) and tried to explain it. They found that the rate of adoption is an increasing function of time during which the new innovation has been available. More specifically, they found that this function is S shaped, and its exact parameters depend on economic variables.

Figure 6.5: The process of technology adoption and diffusion



The adoption function is generally

$$P(t) = K\left[1 + e^{-(a+bt)}\right]^{-1} \tag{6.1}$$

where:
$P(t)$ is the rate of diffusion at time t,
K is the equilibrium rate of diffusion, function of profit (cost and price); and
b is the rate of growth in adoption.

The function in (6.1) corresponds to a logistic process and at each moment the log–ratio of adopters to non–adopters is a linear function of time:

$$\log \frac{P}{K - P} = a + bt \tag{6.2}$$

This formulation allows for the use of a simple regression in applied analyses.

6.2.2 Mansfield model

Mansfield develops a framework to explain the S–shaped diffusion curve. He assumes that diffusion is a process of information transfer. The more you know about it, the more you want to try it. Mansfield uses a model of a spread of an epidemic to simulate the spread of a technique. He considers an industry with n identical firms. The number of firms adopting from 0 to t is $m(t)$. The number of non–adopters is $n - m(t)$. The rate of adoption at time t is defined by

$$\frac{\Delta m(t)}{n - m(t)},$$

that is, the percentage of adopters at time t among the non–adopters.

He assumes that

$$\frac{\Delta m(t)}{n - m(t)} = f(s_t, \pi, \frac{m}{n})$$

where s_t is the cost of introducing the new technology, π is the level of profit an $\frac{m(t)}{n}$ is the rate of diffusion.

Mansfield developed a Taylor series of f, discarded all elements of order greater than second, and got:

$$[\ldots]$$

where the rate of diffusion coefficient is $b = \alpha_0 + \alpha_1\pi + \alpha_2 s$.

To solve for $m(t)$, Mansfield moved to infinitesimal changes and got a differential equation

$$\frac{dm(t)}{dt} = [n - m(t)]\left[A + b\frac{m(t)}{n(t)}\right].$$

He solved it and got

$$\frac{m(t)}{n(t)} = \frac{e^{\gamma+(A+b)} - A/b}{1 + e^{\gamma+(A+b)t}}$$

where γ is the integration constant. Since he assumes no adoption at the start of time, $\lim_{t\to-\infty} m(t) = 0$.

A is equal to zero since

$$m(t) = n(t)\frac{e^{\gamma+(A+b)} - A/b}{1 + e^{\gamma+(A+b)t}}$$

and only $A = 0$ yields $m(-\infty) = 0$. Thus,

$$m(t) = n(t)\frac{e^{\gamma+(A+b)}}{1 + e^{\gamma+bt}} \Rightarrow \frac{m(t)}{n(t) - m(t)} = \frac{1}{1 + e^{-(\gamma+bt)}}$$

and this is a logistic curve.

Mansfield predicts that the proportion of adopting firms will be the S-shaped curve of time. The S curve is symmetrical, and the rate of diffusion quickens as the new technology becomes more profitable and the cost of adoption process declines since

$$b = a + b_1\pi + b_2 s.$$

While Mansfield's model is elegant and nice, it seems unsatisfactory because:

1. It assumes identical firms. It ignores differences between firms because of size, wealth, and education. Another paper by Mansfield showed that these differences matter.

2. There is no mention of the dynamic aspect of adoption:
    - Learning-by-doing reduce investment cost.
    - Over time, capital good cheapen, compared to labor.

3. There is no explicit economic behavior.

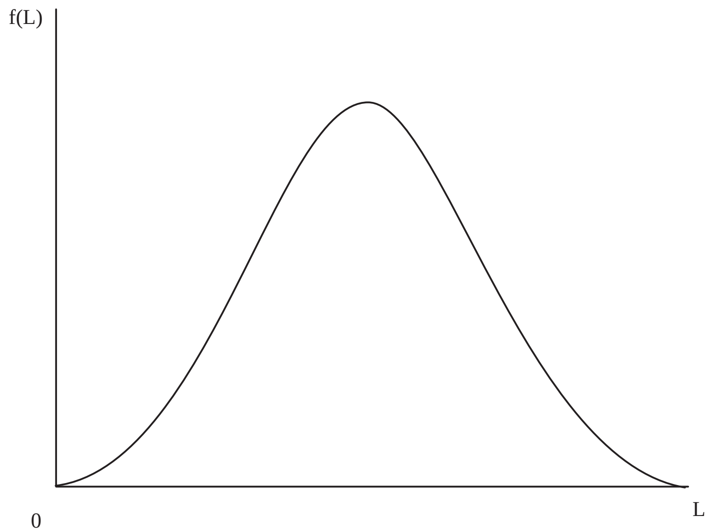
6.2.3 Davis, Effi and Zilberman model

An alternative model is provided by **Davis, Effi and Zilberman**.

Suppose there are two possible technlogies, the old one, which assures a net revenue π_0 per acre, and the new one, which yields π_1 per acre. $\pi_1 > \pi_0$. There is a fixed cost of I dollar to adpt the new technology. You invest if

$$L(\pi_1 - \pi_0) > 0$$

Figure 6.6: Bell–shaped land size distribution



where L is farm size.

If farms have a land size distribution such that depicted in figure 6.6, there will be a critical size

$$L^* = \frac{I}{\pi_1 - \pi_0}$$

above which all firms will adopt.

As time moves on, L^* declines because of:

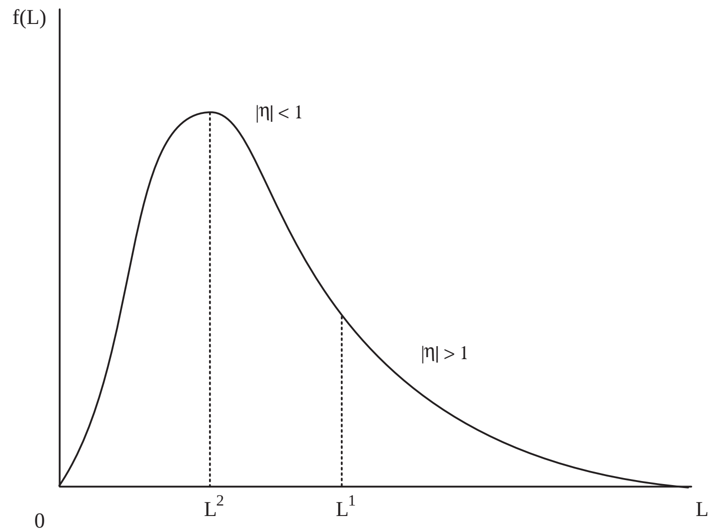
- Learning-by-doing;
- Reduction in cost of capital.

When the distribution of land size is log normal and $\dot{L}^*/L^* = -\alpha$, you will have an S-shaped distribution. Even if the land size distribution is Pareto and $\dot{L}^*/L^* = g(t)$, with $g > 0$, $g' < 0$ and $g'' > 0$, the resulting diffusion curve will be S-shaped.

Thus, we can conclude that the shape of the diffusion curve depends on:

1. The elasticity of the density function of land, $\eta = \frac{f'}{f}L$; in case of log normal distribution, we have $|\eta| > 1$ for $L > L^1$ (cfr. figure 6.7) and then $\eta < 1$, $L^2 < L^1$. The result ...

Figure 6.7: Bell–shaped land size distribution



2. The dynamics of $\frac{\dot{L}}{L}$. It depends on:
   (a) The dynamics of the fixed cost;
   (b) The dynamics of the profit.

   If fixed costs decline at a decreasing rate (because of reduction in price of capital), or profit differential increases at a decreasing rate (decreasing marginal productivity of learning-by-doing), we may have a situation of $\dot{L}L = g(t), g' < 0, g'' > 0$.

Extensions of the Davis *et al.* Model

1. Firms differ in other variables besides land sizes: (a) capital credit endowment and (b) human capital. These differences may account for the observed variability or behavior among farms with the same size.

2. Firms may partially adopt some new technology (i.e., hybrid corn). One has to build a model which can account for it. Uncertainty will be one explanation for partial adoption, as Feder and O'Mara will show in a forthcoming article.