# THE PROCESS OF AN INNOVATION CYCLE

BY

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# The Process of an Innovation Cycle*

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**An economic theory of the process of diffusion of innovations is developed and illustrated. In the theory, adoption is determined by comparative advantage considerations. An innovation is first adopted by skilled and experimenting entrepreneurs and then "diffuses" down the skills scale. If the innovation affects supply substantially, prices may decline, profits eliminated, and early, skilled (and high labor opportunity cost) producers may exit from the affected line of production—hence, an "innovation cycle." The theory implies that technological change is affected by the distribution as well as by the average level of skills.**

ONE would expect comparative advantage considerations—dynamic as well as static—to be crucial in determining patterns of adoption of innovations. This has been recognized in empirical work by, for example, Griliches [2], Mansfield [6] and Nelson [8] who incorporated measures of such items as benefits, costs, and profits as explanatory variables in the analysis. The most explicit recognition of the role of comparative advantages in the adoption of innovations is found in the theory of the "product cycle" in international trade as expounded by Vernon [12] and Hufbauer [3]. The present study is an analysis of a similar process within one industry. A formal model describing an "innovation cycle" is developed in the first part of the paper and illustrated by an example from agriculture in the second.

The model concentrates on the main aspects of the analysis and is based on simplifying assumptions. It is assumed that the innovation is either a new product or a new method that appreciably affects the supply of an existing product. The industry is competitive and is composed of small firms. Producers with the highest skills (the better schooled, perhaps) will be first to adopt the innovation. Their advantage is in spotting a good idea, experimenting with it, and solving problems of adaptation to local conditions. As industry's experience accumulates, others adopt. The increasing supply reduces price. This will drive the first adopters (the highly skilled and high labor opportunity cost producers) out of the production of the new product—hence, an "innovation cycle."

A major implication of the model is that skills are more important the more dynamic the economy. This notion is also developed by Nelson and Phelps [10] and Welch [13], who distinguishes between the "worker effect" (increasing production from an existing bundle of inputs) and the "allocative effect" of schooling (improving the allocation of inputs and outputs). Welch argues that in a technologically stagnant economy experience will lead to optimal allocation in all firms and that schooling's economic contribution will be limited to the worker effect.

In the innovation cycle model the allocation problem is timing the adoption of the innovation, but there is a slight difference between Welch's formulation and that of the authors. In his analysis, lesser-schooled producers simply make allocation errors; in this analysis, they know (or estimate) their lower efficiency in production. In this respect the present model is in line with the traditional economic approach of perfect knowledge and equilibrium: producers act rationally, being aware of their abilities, and firms are always in equilibrium (not necessarily static), while the other diffusion models that have been proposed assume, explicitly or implicitly, disequilibrium and lags in adoption originating from lack of realization on the part of the producers of potential benefits in new factors or products.[1]

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[1] These distinctions are not essential to the model. One could derive the same results on the assumption that lower skilled producers are as efficient as others in production but unaware of opportunities. The policy implications (in terms of the direction of extension work, for example) are quite different. See also [9, p. 102] for evidence that nonadopters are aware of innovations.

### Specification

The model consists of three building blocks: the firm, the product, and the industry. For the sake of exposition it is assumed that technology is stagnant apart from the introduction of the innovation.

*The firm* is defined by an initial endowment of the entrepreneur's own labor, $L_i$ in firm $i$, and skills, $E_i$. All other factors are bought freely on the market; the industry is competitive, and firms do not have monopoly or monopsony power. The firm produces several products and complementarity between skills and other factors of production is assumed; thus, the shadow price (opportunity cost), $w_i$, of the entrepreneur's own labor (a joint input of "raw labor" and skills) is an increasing function of his skills:

$$
\begin{aligned}
&w_i = w(E_i) \\
&w'_i > 0.
\end{aligned} \tag{1}
$$

*The product* $q$ is produced by own labor, $L$ (measured in labor units), and by other factors (including land and capital), $v$ (in dollars), in a production function in which a knowledge component, a function $g$, enters in a multiplicative form (Hicks-neutrality is assumed):

$$q = f(L, v)g. \tag{2}$$

The knowledge factor is a function of skills and the Arrow-type learning by doing [1]. Learning is proportional to the experience at the industry level,[2] $H$,

$$H(t) = \int_0^t Q(s)ds \tag{3}$$

where $Q$ is the total industry output of the new product, and time is measured from the introduction of the innovation.

Since $w$ is a one-to-one function of $E$, it will be convenient to substitute $w$ for $E$ and write the knowledge function as

$$g = g(w, H), \tag{4}$$

with the following restrictions:

$$0 \leq g \leq 1$$

$$\frac{\partial g}{\partial w} \geq 0, \frac{\partial^2 g}{\partial w^2} \leq 0$$

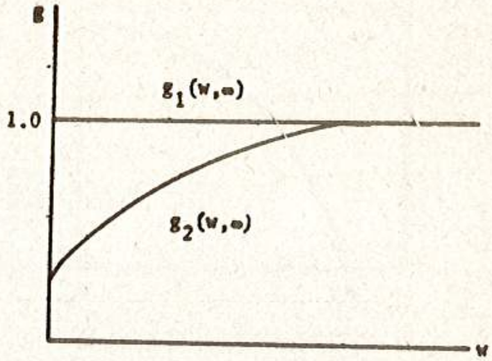


Figure 1. Knowledge functions with maximal experience

$$\frac{\partial g}{\partial H} > 0, \frac{\partial^2 g}{\partial H^2} < 0$$

$$\lim_{H\to\infty} \frac{\partial g}{\partial H} = 0.$$

With these restrictions, equation (2) is a two-stage production function. In the first stage, skills and experience are combined in a "well-behaved" production function to create a knowledge component that is combined in the second stage with the physical process to produce the final product.

This specification is not limited to the new product under consideration; other products were also new in the near or remote past. Write $g(w, \infty)$ for knowledge with maximal amount of learning. Two general classes of products can be distinguished (Fig. 1). In the first class (perhaps wheat growing), $g_1(w, \infty) = 1$. Given enough experience, all producers will possess the same level of knowledge specific to the production of this product. Here experience can completely substitute previously acquired skills. In the second class (radio manufacturing, say), $g_2(w, \infty) < 1$ for some range of $w$. Here a "worker effect" exists in the production of the product. The assumption of complementarity between skills and other factors in a technologically stagnant economy, introduced earlier, implies existence of a "worker effect" in at least some of the firm's products.

*The industry* is competitive but faces a downward sloping demand curve for the new product with the price

[2] Whether experience at the industry level is relevant for the individual's knowledge function depends on the industry's organization. In modern agriculture, with strong public and commercial extension service, industry's experience is probably more important than the individual producer's.

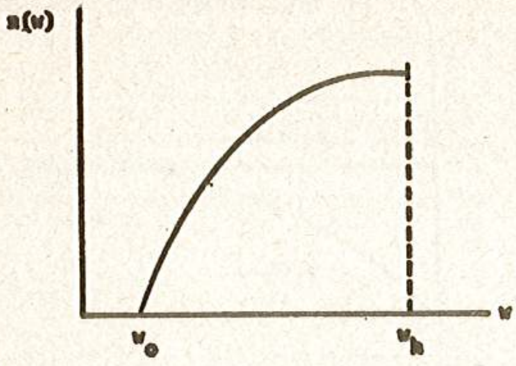


Figure 2. Accumulated distribution of producers

$$P = P(Q) \tag{5}$$
$$P' < 0.$$

Producers in the industry can be ordered by skills (shadow price of own labor). Let $n(w)$ be the number of producers with shadow price $w$ or less. Cumulative function $n$ is nondecreasing; assume it to be differentiable (Fig. 2). If $w_o$ is the lowest in the industry and $w_h$ the highest, then $n(w_o)=0$, and $n(w_h)$ is the total number of producers in the industry. The function $n'(w)$ ($\equiv dn/dw$) is the frequency distribution of producers. The particular form depicted in Figures 2 and 4, in which $n'$ is diminishing with $w$, implies greater concentration of producers in the lower skill range.

## Profits and Final Distributions

Generally, producers will adopt the new product if it is profitable and will increase production if profits increase. But to focus on the essentials and to reduce mathematical complexity, assume that a new product is produced in all firms by identical and fixed amounts $\hat{L}$ $\hat{v}$ of physical inputs. Let

$$\hat{q} = f(\hat{L}, \hat{v}) \cdot 1$$

be the output of a firm for which $g(w, H) = 1$, that is, a firm with maximum knowledge. Assume further that introduction of the new product does not alter $w$, the shadow price in the other lines of activity in the firm; then profits above alternative costs in the new product in firm $i$ are

$$\pi_i = P\hat{q}g(w_i, H) - w_i\hat{L} - \hat{v}. \tag{6}$$

The firm will produce only if profits are positive:

$$q_i = \hat{q}g(w_i, H) \qquad \pi_i > 0$$
$$q_i = 0 \qquad \pi_i \leq 0.$$

With this study's assumptions profits will increase with $w$ for low levels of the shadow price and decrease for higher levels (Fig. 3). Let $\underline{u}$ and $\bar{u}$ be the lowest and the highest $w$ values for which $\pi(w)=0$. [When the diffusion process starts, profits are positive for the highest skilled operators; therefore, set $\bar{u}=w_h$ if $\pi(w)=0$ for $w>w_h$. Similarly, set $\underline{u}=w_o$ if $\pi(w)=0$ for $w<w_o$.] Production will take place by producers with shadow prices on the range ($\underline{u}$, $\bar{u}$). With time, experience accumulates, production expands, and prices fall. In the innovation cycle process, falling prices drive highly skilled (and wage) producers out, while low-skilled producers benefit from experience and adopt the innovation.

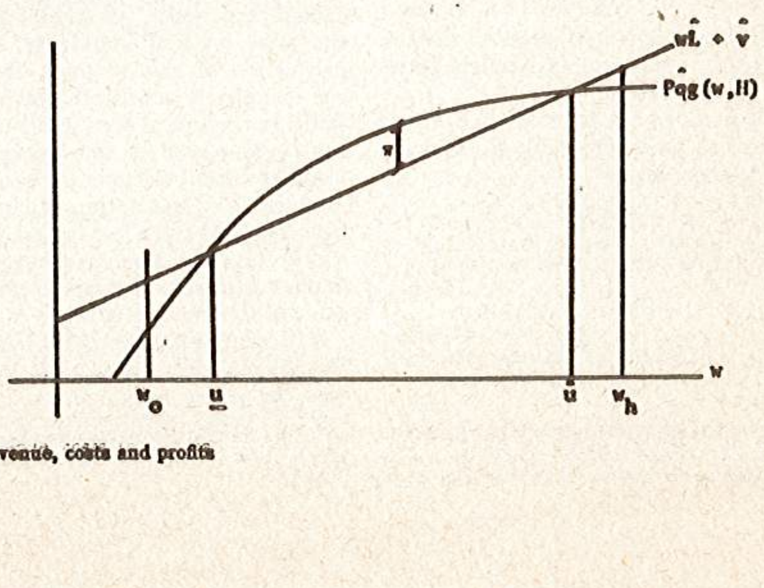


Figure 3. Revenue, costs and profits

To trace the innovation cycle, focus on the movement of the boundaries, the break-even points $\underline{u}$, $\bar{u}$. For these points $\pi = 0$ always. Differentiating equation (6) with respect to time, incorporating $\dot{\pi}(\equiv d\pi/dt) = 0$ and writing $\partial g/\partial u$ for $\partial g/\partial w$ evaluated at $u$,

$$\text{(7)} \qquad \dot{u} = \frac{P'Q\hat{q}g(u, H) + P\hat{q}\dfrac{\partial g}{\partial H}Q}{L - P\hat{q}\dfrac{\partial g}{\partial u}} \qquad (u = \underline{u}, \text{ or } u = \bar{u}).$$

In other words, for $\underline{u}$ and $\bar{u}$,

$$\dot{u} = \frac{\text{market effect} + \text{learning effect}}{-\dfrac{\partial \pi}{\partial u}}.$$

For $\bar{u}$, the (negative) market effect is stronger than the (positive) learning effect and $\partial\pi/\partial u < 0$, thus $\dot{\bar{u}} < 0$. With a learning effect stronger than market effect and $\partial\pi/\partial u > 0$ (Fig. 3), $\dot{\bar{u}} < 0$ also. At the beginning of the diffusion process, $\bar{u} = w_h$ and $\dot{\bar{u}} = 0$ until highly skilled producers begin to exit.[3]

The innovation cycle may continue until $\underline{u} = w_o$, but this is not the only possibility. Several alternative *final* distributions of producers (attained after the completion of the diffusion process) can be distinguished. Four such cases are depicted in Figure 4. Case (c) is an innovation cycle as described above. In case (a) the demand is highly elastic and skilled producers did not exit at all. In cases (b) and (d) the innovation cycle stopped at $\underline{u} > w_o$. A necessary condition for this is the existence of a worker effect $[g(w, \infty) < 1]$ in the new product, so that low-skilled producers can never, not even with maximal industry experience, master the profitable production of this product.

## Further Dynamics

Total product of the industry is

$$\text{(8)} \qquad Q = \int_{\underline{u}}^{\bar{u}} n'(w)\hat{q}g(w, H)\, dw.$$

Taking a time derivative of $Q$, incorporating (7), and making use of $\dot{H} = Q$, one obtains:

$$\text{(9)} \quad \frac{Q}{Q} = \phi(Q, H) =$$

$$\frac{\left(\hat{q}\displaystyle\int_{\underline{u}}^{\bar{u}} n'(w)\frac{\partial g}{\partial H}\, dw + P\hat{q}^2\right.}{1 - P'\hat{q}^2\left[\dfrac{n'(\bar{u})g(\bar{u}, H)^2}{-\dfrac{\partial\pi}{\partial\bar{u}}} - \dfrac{n'(\underline{u})g(\underline{u}, H)^2}{-\dfrac{\partial\pi}{\partial\underline{u}}}\right]}$$

$$\left.\cdot\left[\frac{n'(\bar{u})g(\bar{u}, H)\dfrac{\partial g}{\partial H}}{-\dfrac{\partial\pi}{\partial\bar{u}}} - \frac{n'(\underline{u})g(\underline{u}, H)\dfrac{\partial g}{\partial H}}{-\dfrac{\partial\pi}{\partial\underline{u}}}\right]\right)$$

It can be shown that $\phi(Q, H) \geq 0$. The solution to (9) is

$$\text{(10)} \qquad Q(t) = \exp\left[\int_0^t \phi(Q, H)ds + c\right]$$

with

$$Q(0) = \exp(c).$$

Equation (9) in its present form is applicable when the innovation cycle proceeds with producers entering and others dropping the production of the new product. At the beginning of the process, before the exit of the skilled producers, or always in cases (a) and (b) in Figure 4, $\bar{u} = w_h$ in the integral in equation (9) and other terms involving $\dot{\bar{u}}$ vanish (since $\dot{w}_h = 0$). When $\underline{u} = w_o$ in case (a), or in all other cases when movement of producers in or out stops, $Q$ will continue to grow as a result of learning at the rate

[3] For the innovation cycle proper to exist, that is, for the innovation to move from highly skilled producers who drop it to low skilled ones who adopt it, the market effect at $\bar{u}$ has to be stronger than the learning effect. If this is not the case, highly skilled producers will never drop the new product. These alternative possibilities will be reflected in different final distributions as exemplified in the next section in the text.

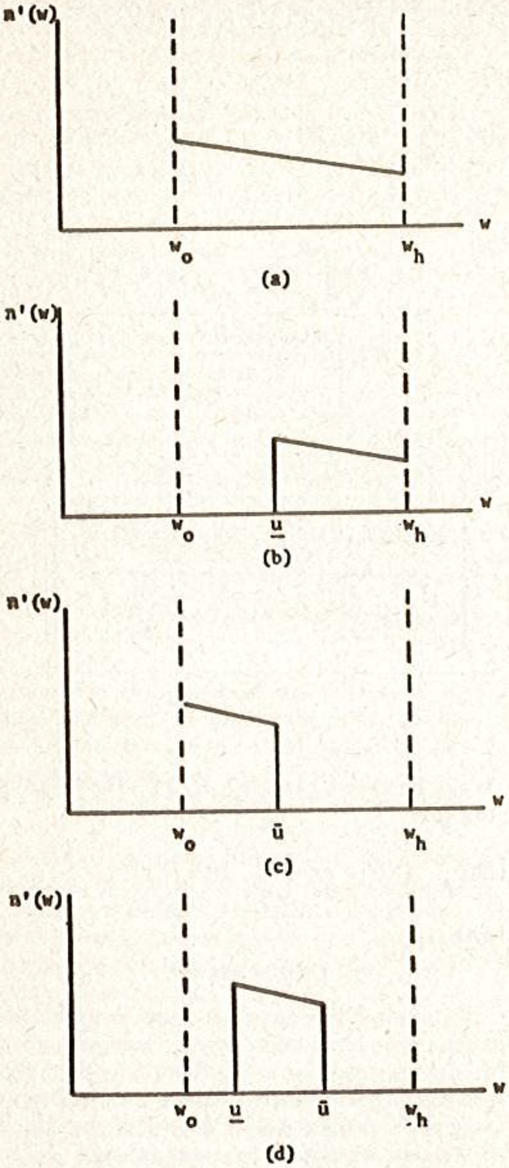


**Figure 4. Final distribution of producers [with $g(w, \infty)$]**

$$(9.1) \qquad \frac{\dot{Q}}{Q} = \hat{q} \int_{\underline{u}}^{\bar{u}} n'(w) \frac{\partial g}{\partial H} dw$$

until $\partial g/\partial H$ vanishes. [$\dot{Q}$ can be expected to have discontinuities and $Q$ "kinks" where producers start or stop to exit; and, strictly speaking, the integral in equation (10) is calculated between such discontinuities.]

Unlike other diffusion models proposed [6, 8], the present one does not yield a logistic time pattern. In some cases, however, an $S$-shaped function can be expected. In all, $\dot{Q}$ will eventually approach zero as time passes and $\partial g/\partial H \to 0$ for all levels of $w$. When the process starts, $P'$ will in many cases be comparatively low due to shifts in short-run demand associated with the market's growing familiarity with the new product, and $\dot{Q}$ can be expected to grow approximately in proportion to $Q$ (particularly so long as $\bar{u} = w_h$). These two effects, at the beginning and the end of the process, may be expected to generate an S-shaped time pattern of production.

If production of the new product can be expected to taper off asymptotically as experience accumulates, this will not be the general rule with respect to the number of producers, particularly not in cases (a) and (c). Let the number of producers be $N$,

$$(11) \qquad N = n(\bar{u}) - n(\underline{u}).$$

Then

$$(12) \qquad \dot{N} = n'(\bar{u})\dot{\bar{u}} - n'(\underline{u})\dot{\underline{u}}.$$

In cases (a) and (b) in Figure 4

$$(13) \qquad \dot{N} = -\frac{n'(\underline{u})}{-\frac{\partial \pi}{\partial \underline{u}}} \left[ P'Qqg(\underline{u}, H) + Pq \frac{\partial g}{\partial H} \dot{Q} \right].$$

$\dot{N}$ is positive since the learning effect is stronger than the market effect (see equation 7). But $\dot{N}$ can actually *increase* as $\underline{u} \to w_0$ if $n'(w)$ is high for low values of $w$ (this is the assumption in Figures 2 and 4), reflecting higher concentration of producers in the lower skilled groups. One could expect a general sigmoidal form of $N$ in time in cases (b) and (d) with entry rates increasing at the beginning of the process and then starting to decline as the skilled producers exit, not necessarily converging asymptotically to zero.

On theoretical grounds these results are inconsistent with the common observations that fit nicely logistic time patterns. The reason may be in the neglect in the present model of the imitation component [6], which is a factor that associates the rate of adoption with the ratio of the number of potential adopters to those who had already adopted. This implies that the diffusion process is affected by the intensity of interactions between these two

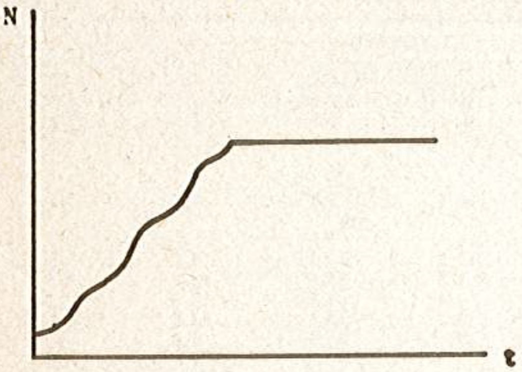


Figure 5. Possible time pattern of $N$

groups.[4] But on practical grounds, this inconsistency should not be exaggerated. With errors in observations and in the behavior of producers (who make their decisions according to next season's expected prices) the judgment between the alternative models is not easy. Observations generated by a theoretical time pattern as in Figure 5 can look rather consistent with a logistic function, and in empirical work such a function can be the most suitable for summarizing the diffusion information. (This is the approach followed in the application below.)

### Remarks

Profits made by the first adopters of a new product can justifiably be regarded as rent to innovativeness. Whether the final producers of the new product will enjoy higher incomes in the long run depends on the cross elasticity of demand between the new product and other products of the industry, and (relaxing the assumption of a fixed number of producers) on the elasticity of supply of similarly skilled producers who may be lured into the industry by persistent profits. If these two factors are unimportant, introduction of the new product will increase profits in the long as well as in the short run. (If inputs are not fixed, introduction of the new product will alter shadow prices, profits in competitive equilibrium will vanish, but incomes can be higher than before introduction of the innovation.)

The boundary between rent to innovativeness and additional income to noninnovating latecomers is not clear cut. But, it is worth reemphasizing that the returns to highly skilled producers from early adoption are over and above what they earn in other lines of production. These returns are transitory; to maintain them, skilled producers have to search continuously for new ideas and products.

From the social point of view, rent to innovativeness is a payment for skills (investment in schooling and training), for efforts in adaptation, and for risk-taking. The last elements do not appear explicitly in the model. The innovation cycle raises interesting welfare issues. (Should optimal *level* of schooling be a policy goal or should it be optimal *distribution* of human capital?) But these are also outside the scope of the present paper.

### An Illustration[5]

The model is illustrated with diffusion of an innovation in agriculture in Israel. The innovation is the technique of growing winter vegetables (tomatoes, cucumbers, peppers—which had been in limited supply) under plastic covers. Protective tunnels constructed from long sheets of plastic material supported by wood or metal frames were introduced from Japan and first tried in an experimental station in the mid-1950's. By the mid-1960's the innovation had reached all sectors of the industry. Integration of new areas after the Arab-Israeli War in June 1967 altered market conditions in agriculture in Israel. Therefore, the period of study was not extended past 1967.

Ideally, to test and illustrate the innovation cycle model, one would utilize such data as skill (schooling) of farmers, size of farm operation, labor opportunity cost, and dates of adoption and exit. Such data are not available (though many are known to have adopted and then stopped using the innovation when profits declined). The data reported are areas planted to winter vegetables by sector in the Israeli agriculture for the period 1958/59 to 1966/67. These sectors are characterized by distinct socioeconomic traits,[6] and the illustration is mainly a comparative analysis of the sectorial diffusion process. Table 1 presents distributions

[4] The crucial assumption in the present model in this respect is that experience diffuses freely (all firms have the same $H$). Imitation can be introduced into the model, for example, by making learning by nonadopters a function of the ratio of adopters to total number of producers.

[5] For details see [5].

[6] See [4, 14] for detailed descriptions and additional references.

Table 1. Sectorial distribution: schooling, selected product shares, and capital-labor ratios

| | Capital-labor ratio in activity | *Kibbutzim* | *Moshavim* | | Private | Arab Sector |
|---|---|---|---|---|---|---|
| | | | Established | Young | | |
| 1. *Median year of schooling* (males 14 years and over) | | 11.0 | 10.1 | 7.5 | 7.4 | 5.2 |
| *Capital-labor ratio* (IL/day)[a] | | | | | | |
| 2. Overall[b,c] | | 11.9 | 6.6 | 5.9 | 4.7 | 3.3 |
| *Share in product* (%) | | | | | | |
| 3. Total farm product | | 34.1 | 12.1 | 27.7 | 19.3 | 6.8 |
| 4. Vegetables | 2.4 | 8.7 | 7.5 | 54.6 | 20.7 | 8.5 |
| 5. Winter grains | 70.0 | 73.0 | 1.4 | 14.1 | 10.3 | 1.2 |
| 6. Citrus | 4.5 | 19.0 | 13.7 | 22.4 | 44.1 | 0.8 |
| 7. Dairy | *kibbutz* 21.9 *moshav* 11.9 | 37.4 | 19.1 | 40.6 | 2.9 | — |
| 8. Covered vegetables 1961/62 | | 17.2 | 22.9 | 27.5 | 32.4 | — |
| 9. Covered vegetables 1966/67 | | 6.2 | 17.3 | 41.8 | 26.0 | 8.7 |

[a] Capital-labor ratios are ratios of capital outlays in IL (depreciation, machine rentals, maintenance, etc.) to number of labor days per unit of production; structures are included but land is not.
Data are from cost accounts, constructed and used for planning purposes. Where available (dairy, for example) different figures were used for the different sectors in calculating line 2.
[b] Data for lines 2–7 are for 1965.
[c] Line 2 pertains only to farming operations (the industrial sector in the *kibbutz* is not included).
Sources: Line 1: State of Israel, Central Bureau of Statistics, *The Settlements of Israel*, Part VI; Population and Housing Census 1961, Publication 28, Table 9.
Lines 2–7: Center for Agricultural and Settlement Planning, Ministry of Agriculture, Tel Aviv.
Lines 8–9: Vegetable production and Marketing Board, Tel Aviv.

of schooling, capital-labor ratio, lines of activities, and areas of vegetables under plastic covers. The following are a few additional descriptive remarks.

A *kibbutz* (plural: *kibbutzim*)[7] is a communal settlement of 200 to 2,000 inhabitants in which production and consumption are collective. The scale of operation is large, permitting members to specialize in a single line of production. Technology is advanced, and schooling and capital-labor ratio are the highest in the industry (Table 1).

The other cooperative sector is the *moshavim* (singular: *moshav*). In the *moshav*, farms operate their private family farms and cooperate in marketing and the purchasing of inputs and services. Schooling and capital intensity in the *moshav* are lower than in the *kibbutz* (Table 1), scale of operation is much smaller, most farms are diversified, and operators manage 3 to 4 lines of production (field crops, livestock, orchards, etc.). "Established" *moshavim* were founded in the 1920's and 1930's before the creation of the State of Israel (1948). The "young" *moshavim* were established after 1948. Most of their members immigrated to Israel in the 1950's with no prior agricultural experience.

The cooperatives, *kibbutzim* and *moshavim*, try to adhere to the principle of self-labor to avoid exploiting the work of others. Though this principle is not followed equally by all, it imposes a certain restriction for these settlements. *Private* (Jewish) agriculture, on the other hand, is based to a large extent on hired labor including seasonal employment. This is one of the reasons for lower capital-labor ratio in this sector than in the *moshav*.

The *Arab* is the only traditional farm sector in Israel. Levels of schooling and capital-labor ratio are the lowest in the industry (extended families contribute low opportunity-cost labor). This sector had in the past concentrated on dry farming, and irrigation (necessary for intensive vegetable production) is still not as widespread as in most of the Jewish farms.

Though markets, particularly for land and capital, are not perfect, data in Table 1 are consistent with basic assumptions of the model. Capital-labor ratios are positively correlated with schooling, and distribution of farm activities differs from sector to sector in agreement with sectorial comparative advantages, strengthening in this way the conjecture of a

[7] The sector of *moshav shitufi* with collective production and private consumption was included with the *kibbutz*.

rising labor-opportunity-cost with schooling. Innovativeness is also in strong agreement with the model's assumption. The *kibbutzim* are by far the most innovative [7]. Young *moshavim*, being less experienced and schooled, are less innovative than the established ones. The private sector has a more diversified record in this respect, with some farmers very progressive and others far behind. The traditional Arab sector is generally the last to follow.

Early stages of adoption of plastic covers were also in line with these general patterns. The innovation was first picked up by several entrepreneurial private farmers who were close to the university and the experimental station and by a few *kibbutzim*. Early stages were characterized by experimentation, learning (the right kind of plastic material, optimal timing of treatments, appropriate soils, etc.), and by more than a few disappointments. Perhaps typical of the kind of activities that form the industry's learning process at the different skill levels are: a *kibbutz* that operated a factory for plastic products developed and tested sheeting for covers and a tractor-mounted implement to construct the protective tunnels mechanically; and a great majority of hired laborers in the private sector were Arab villagers who on their jobs had the opportunity to learn by doing, and thus could bring the innovation back to their own farms.

If sectors were homogeneous with no intrasectorial differences in skills and other initial endowments, then, by the model all farms in a sector will adapt simultaneously at the same time. But the sectors, though markedly distinct, are not homogeneous—some *kibbutzim* have comparatively low labor opportunity costs, for example. Also, with experience, producers specialized and increased the volume of production—a possibility abstracted from the model. Therefore, in terms of the data, the innovation cycle is manifested as shifts in relative sectorial shares of production.

By 1961/62, *moshavim*, established and young, planted half the covered winter vegetables (Table 1, line 8). By 1966/67 the share of the *kibbutzim* had declined substantially, and the shares of the young *moshavim* and the Arab sectors had increased to a level larger than the shares of these sectors in total farm product. (The corresponding shares for the last two sectors for 1970/71 were 46.3 and 25.6 percent, respectively.) Similar findings are reported in Table 2 which gives estimates of the logistic

Table 2. Estimated values of the sigmoidal function

$$y_t = \frac{k}{1+be^{-at}}\text{}^{a}$$

| | $k$ | $b$ | $a$ | $\frac{k}{1+b}$ | *$R^2$ |
|---|---|---|---|---|---|
| *Kibbutzim* | 571 | 15 | .588 | 35.8 | .983 |
| *Moshavim:* Young | 3,633 | 233 | 1.257 | 15.5 | .990 |
| *Moshavim:* Total | 6,233 | 99 | .979 | 62.3 | .994 |
| Private | 1,935 | 132 | 1.585 | 14.6 | .978 |
| Arab sector | 852 | 464,580 | 3.850 | 0 | .974 |
| Tomatoes | 5,196 | 202 | .998 | 25.7 | .993 |
| Cucumbers | 3,257 | 64 | 1.153 | 49.8 | .988 |
| Peppers | 1,837 | 3,654 | 2.077 | .5 | .979 |

[a] Data are annual observation [area planted, in dunam (=0.1 hectare)] 1961/62–1966/67, except for cucumbers and peppers for which data were available starting with 1958/59 season. $y_t$ area in year $t$; $k$, $a$, $b$ parameters; and *$R^2$ correlation coefficient between the calculated and observed $y$ values. Estimated by the method suggested by Tintner [11, pp. 208–211].

The equation for the established *moshavim* did not have a real value solution; the estimates for the pooled data of the total area in the *moshav* sector are reported.

function parameters (graphical examination confirmed the logistic time pattern of the diffusion process [5]). The intercept [the parameter $k/(1+b)$] is zero for the Arab sector and low for the young *moshavim*. The table also reveals a higher rate of adoption (the parameter $a$) for the latecomers—the Arabs, the private growers, and the young *moshavim*—a faster rearrangement in positions of static comparative advantages than rates of early (experimental) adoptions. One explanation for this (suggested by Welch) is that the variance of skills distribution is lower in these sectors, causing a speed-up of the diffusion in the lower skilled groups [consistent with the form of $n(w)$ in Figure 2].

The diffusion process is completed when the market is in long-run equilibrium. In addition to estimates of the sigmoidal equation reported in Table 2, the same function was estimated from the same data set imposing projected equilibrium $k$ values, explicitly recognizing in this way the equilibrating properties of the process.

The basic approach was simple. It was assumed that long-run supply curves of winter vegetables were horizontal. Costs of production were accordingly estimated for each crop from technical data employing market wage rates.[8] Demand functions were estimated for the marketing season of plastic-covered crops. Equilibrium quantities were then calculated for each crop. Limited amounts of winter vege-

[8] We assume that the 1968 data used already incorporated $g(w, \infty)$ and that production would be concentrated in the hands of producers whose $w$ equals the market labor wage rate.

**Table 3. Equilibrium estimates of the diffusion equation[a]**

| | Tomatoes | Cucumbers | Peppers |
|---|---|---|---|
| *Projected Equilibrium Values:* | | | |
| Total product (tons) | 16,652 | 5,368 | 3,122 |
| Area (dunams) | 3,965 | 3,158 | 1,388 |
| *Regressions:* | | | |
| No. of observations | 5 | 8 | 7 |
| $a$ | .878 | .913 | 1.131 |
| | (7.752)[b] | (8.299) | (26.782) |
| $b$ | 79.2 | 207.5 | 455.0 |
| | (12.275) | (9.620) | (44.603) |
| $*R^2$[c] | .960 | .912 | .949 |

[a] Data are the same as in Table 2. The equation

$$y = \frac{k}{1 + be^{-at}}$$

was estimated in the form $\log (k/y - 1) = \log b - at + u_t$.
[b] Values in parenthesis are $t$ values.
[c] $*R^2$ is the correlation coefficient between the calculated and observed $y$ values.

tables were obtained from unprotected fields in the warm inner valleys of the country, and these quantities were deducted from the equilibrium supply of plastic-covered vegetables. Dividing by average yield, equilibrium areas were projected. These areas are reported in Table 3 together with the estimated parameters.

The projected market equilibrium areas (Table 3) were lower than those obtained from the estimates (the parameter $k$ in Table 2). This should be expected when individual growers do not perceive the market mechanism and underestimate the coming reduction in income. Rates of expansion are also consistently lower in Table 3. Unfortunately, this study could not be extended to allow detailed analysis of industry's approach to equilibrium. The early stages observed suggest a process of convergence, perhaps of the cobweb type, together with a shift of the distribution of the growers.

## Conclusion

The example in the previous section illustrates that despite its simplifying assumptions, the model is capable of illuminating the economics of the adoption process. The process proceeded, according to comparative advantage positions, from skilled-intensive to labor-intensive producers. Several other innovation diffusion cases in Israel proceeded in a similar pattern (sheep raising, cut flowers, sugar beets). Needless to say, in many other diffusion cases alternative specifications will be more appropriate than the ones adopted here. For example, the effect of knowledge on productivity need not be Hicks-neutral; knowledge may be more important with one input than with others, and this aspect can be crucial in explaining diffusion of capital-intensive innovations. Or, in an industry with a small number of big firms that try to maintain secrecy, adoption of a new idea by a firm will depend more on the firm's own investment in R&D than on the industry's experience. The innovation cycle resembles in many aspects the product cycle in international trade, but for a model to give full account of the product cycle it should contain elements of import, export, national income levels, and similar relevant variables. It seems, however, that the present model can serve, with appropriate modifications, as the basic structure for other variants of the theory.

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