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Induced Innovations and Farm Mechanization

Yoav Kislev and Willis Peterson

There are two traditional explanations to the revolutionary machine-labor substitution in American agriculture. One is that technical change in agriculture caused machines to be introduced and labor to become unwanted. The alternative explanation is that, from the farm sector point of view, labor's exit is primarily a market phenomenon guided by rising urban opportunities and declining real machinery costs.

If mechanization and labor exit are due to technical change in agriculture, then they come mainly from the public agent of farm technology—the agricultural research system; the research system should be held responsible for the social consequences of farm mechanization, and it should be budgeted and directed accordingly. On the other hand, if mechanization and exit from farming are caused mostly by external price and wage changes, the responsibility of the research system is limited principally to technology improvement.

In this note we discuss the newly emerging tradition of induced innovation and its relation to the alternative explanations of machine-labor substitution in agriculture. We first clarify the conceptual basis of the induced innovation hypothesis and the related innovation possibility function. Second, we call into question the validity of some of the empirical applications. We argue that an incomplete conceptualization of the induced innovation idea has led to invalid empirical tests and to inappropriate implications on the causes of American farm mechanization.

The Hicksian Framework

It is useful to view the process of price-induced technical change as if it occurs in two stages. In figure 1 the initial isoproduct curve, I_1, and price ratio, P_1, result in an equilibrium, cost-minimizing combination of capital and labor at point A. As prices change to P_2, the new equilibrium point along I_1 is B. According to the induced innovation hypothesis, this change in relative prices causes an asymmetric shift in the production function. This is represented in the diagram by the shift in the isoquant from I_1 to I_2. Now the equilibrium point is at C for the price ratio P_2. The capital-labor ratio is increased in two stages: from A to B in response to the price change and from B to C in response to induced technical change.

Technological change is a function of the available stock of knowledge and the resources devoted to research and development. The concept of the innovation possibility function (the metaproduction function in the terminology of Hayami and Ruttan) was introduced to formalize these relations. Hicks originally assumed innovation possibilities to be basically neutral; subsequent literature relaxed this assumption (Kennedy). If it is comparatively easier to develop technology that will save relatively more of a single factor, labor for example, one could say that the innovation possibility function is biased in a labor-saving or capital-using direction.

Biasedness need not be associated with price changes. In terms of the diagram, if technological changes took place and the innovation possibility function is biased in a labor-saving direction, then I_1 could shift to I_2 and equilibrium; still with the price ratio P_1, will move from A to D, increasing the capital-labor ratio.

Agriculture and Manufacturing

Much of the new technology that has affected productivity in agriculture was developed in the manufacturing sector and introduced into the farm sector, embodied in new or improved inputs—mechanical and chemical. The aggregate, economywide framework of the induced innovation hypothesis does not account for the intersectoral transfer of technology because the whole economy is taken as one sector. However, when applying the induced innovation idea to a single sector such as agriculture, it may be necessary to separate the sector where the technology is developed from the sector where it is used. Otherwise market phenomena reflecting farmers' responses to relative factor price changes may be mistakenly identified as technical change internal to agriculture.

Commonly, the output of certain manufacturing industries, such as machinery, commercial fertilizer, and other farm supplies, are counted as inputs to the farm sector in productivity studies. Alternatively, however, manufacturing and agriculture could be combined into a single sector. If combined, factors purchased by farmers from the farm

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The authors are, respectively, senior lecturer in economics, Hebrew University, Rehovot, Israel, and professor, Department of Agricultural and Applied Economics, University of Minnesota.

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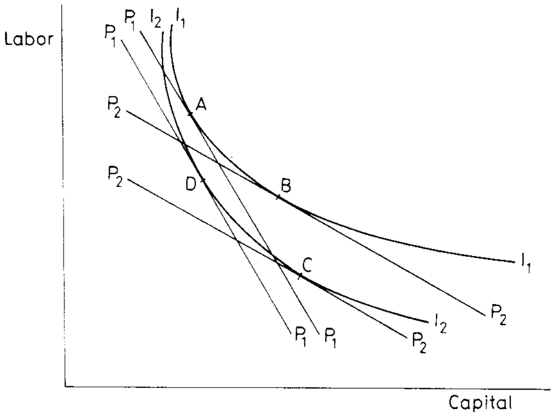

Figure 1. Induced technical change

supply industries will be regarded as intermediate goods, and the extrasectoral inputs will be such things as energy, steel, and raw materials, plus total capital and labor in the combined sector. In fact, the induced innovation hypothesis for agriculture originally was formulated (though not estimated) in the framework of a combined agriculture-manufacturing sector: at least this is how we read the theoretical sections of chapters 4 and 5 of Hayami and Ruttan.

In other cases, particularly if the empirical analysis is limited to agriculture, it is necessary to recognize explicitly that farming and manufacturing are two separate sectors. The induced innovation hypothesis as applied to agriculture should then be interpreted as the assertion that relative price changes induce innovations through two separate channels—external and internal. Innovations in manufacturing represent external technical change to agriculture which may or may not show up in the conventional estimates as productivity gains in the latter sector. If the new technology takes the form of product innovations, and if measures of the new or improved inputs (machines, let us say) do not accurately reflect quality changes, there may be a shift in the estimated agricultural production function as in figure 1. If it is a process innovation, such as the ability to produce nitrogen fertilizer at a lower cost, it may show up as a change in relative prices represented by a movement along an isoquant or production function. Better products often carry higher price tags, but farmers will not purchase the new or improved inputs unless their quality-adjusted prices are lower than the old input prices. Product innovations create, therefore, an identification problem. If these inputs are not adjusted for quality, farmers will be seen as increasing demand—buying more at higher prices. On the other hand, if these inputs are adjusted for quality, farmers will be seen as reacting to shifts in the supply of machine services—buying more at lower prices. In the latter case, there will be no measured technical change in agriculture; all of it will be seen to occur in manufacturing.

It is inconsistent to leave new or improved inputs created by product innovations in manufacturing unadjusted for quality, calling this technical change in agriculture, while treating process innovations which result in lower-priced inputs as a market phenomenon. As far as agriculture is concerned, both types of innovations are the same. Both result in lower effective prices of purchased inputs to farmers. Purchased inputs should therefore be adjusted for quality.[1]

Technical change also may occur in the agricultural sector, particularly if one defines this sector as including the research and development arm of farmers, namely, agricultural experiment stations. One might refer to the production of new varieties of crops, improved breeds of livestock, or new knowledge utilized directly by farmers as internal technical change, Machine-biased internal technical change might occur, for example, if new varieties of crops are adopted which require more mechanical services to insure proper timing of planting or harvest. In this case, farmers actually will increase their demand for machines and buy more of them even at higher real prices. Here, as elsewhere, one would not find productivity growth in agriculture if agricultural inputs were perfectly adjusted for quality. However, there would still be an increase in demand for machinery.

Empirical Application

Hayami and Ruttan did not explicitly separate internal and external technical change in their application of the concept of the induced innovation to agriculture. They were interested in international comparisons, particularly in demonstrating how agriculture of the comparatively capital-rich countries moved in the direction of labor-saving technology and how other countries, such as Japan, constrained by low land-labor ratios, developed and adopted land-augmenting innovations. For this analysis, the single-sector framework was a useful conceptualization and it was not crucial to distinguish between innovations in agriculture and innovations created in manufacturing. (Hayami and Ruttan did, however, discuss at length the mechanism of the transmission of the economic signals from commercial agriculture to the public agricultural research system.)

A detailed application of the induced innovation hypothesis to U.S. agriculture has been carried out by Binswanger for the 1912–68 period. His approach involved a two-stage estimation of the

[1] Quality unadjusted inputs are not only inconsistent in the analysis of technical change; they are simply meaningless. Inputs always should be measured in standard efficiency units. A simple addition of different quality tractors, for example, is as meaningless as adding apples and oranges.

biasedness of technical change in agriculture. First, elasticities of substitution in a five-input model of the farm sector were estimated. The second stage was an attempt to separate substitution of factors along isoquants in response to price changes from substitution due to biased technical change—shifts of the isoquants.

The real price of machinery in Binswanger's study is reported in table 1 (our data are discussed below). In his multifactor analysis, Binswanger employed the ratio of the price of machinery to the aggregate price of all inputs in agriculture. To focus on the machine-labor relation, we calculated from his data the implied ratio of machine price to the wage rate. In general, both ratios exhibit similar trends. The real machine price was comparatively high in the decade of the 1930s, mainly because of the decline in farm wage rates. In both series the real price of machines was higher after World War II than in the 1920s. The series differ in one respect: relative to all inputs, machinery prices are reported to increase substantially after the war: while relative to labor, machinery prices are comparatively stable for this period.

Whether the original five-factor perspective is adopted or the narrower two-input, labor and machinery point-of-view is taken, the data presented in part A of table 1 indicate that machine-labor substitution after World War II could not be a market phenomenon, i.e., it could not be a process of substitution in response to relative factor price changes. Indeed, Binswanger (p. 223) reports "that overall technical change was machinery-using, despite a substantial overall rise in the relative machinery price." These findings imply that internal farm sector technical changes which shifted the demand for machinery were the sole reason for the vast substitution of machinery for labor after World War II.

Table 1: Indices of Real Price of Machinery

	Ratio to			Ratio to	
Year	All inputs	Labor	Year	All inputs	Labor
A. Binswanger					
1912	100	100	1944	121	112
1916	102	103	1948	106	91
1920	84	78	1952	131	110
1924	93	83	1956	140	104
1928	98	83	1960	155	109
1932	141	119	1964	160	107
1936	162	167	1968	154	96
1940	164	161			
B. Custom rates					
1930	100				
1950	56				
1970	35				

Sources: Binswanger, table 7-1; custom rates, Kislev and Peterson, table 3.
Note: Binswanger's data are ratios of machine prices to prices of "all inputs" or "labor." Custom rates are ratios of rates in combine harvesting to agricultural wage rates.

Internal technical changes could have occurred because of learning by doing or the introduction of new crop varieties and other inputs. However, from what we know about U.S. agriculture, it is hard to believe that farm mechanization after World War II should all be attributed to new varieties and similar on-the-farm factors. The development of the machine-adapted tomato varieties, for example, began in 1943, when the shortage of labor was strongly felt (Rasmussen). It is hard to think of other major clear-cut cases. Some of the new chemicals require new machines to apply but at the same time save on machines by reducing tillage work.

The main empirical difficulty we see with Binswanger's analysis is his failure to adjust machinery prices for quality changes. The official U.S. Department of Agriculture (USDA) machinery price index, which he used, has been shown to overstate the increase in machinery prices because quality changes are not accounted for (Griliches, Fettig). The USDA series also overlooks the substantial decrease in the effective cost of mechanical services caused by the increasing importance of income taxes, particularly the accelerated depreciation and investment credit provisions of the tax law. In an attempt to avoid these misspecifications, we collected data on custom rates in combine harvesting. These rates reflect the market evaluation of quality changes and other factors affecting cost of machines service.

The new custom-rate, wage-rate ratio reported in table 1 reveals a large decline in the relative cost of machinery. With these data, the explanation for farm mechanization becomes straightforward. Farmers demanded new and larger machines because the cost of farm labor, both the opportunity cost of family labor and wage of hired labor, increased relative to the prices of machinery services. Machinery manufacturers responded to this increase in demand by expanding capacity through investment in both research and development and plant and equipment. Thus, as we read the evidence, the technical change that encouraged farm mechanization occurred mostly in the manufacturing sector. Had the induced innovation hypothesis been more carefully formulated in terms of the interrelation between agriculture and manufacturing,[2] we believe that empirical work would have distinguished between internal and external technical change, in turn leading to careful quality adjustment of machine price data and in the final analysis would have produced very different findings and policy implications.

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[2] Although Hayami and Ruttan did not distinguish between internal and external technical change, they did adjust for input quality change in their attempt to explain changes in factor proportions in the United States and Japan by changes in factor price ratios (chap. 6).

References

Binswanger, Hans P. "Measured Biases of Technical Change: The United States." *Induced Innovation, Technology, Institutions and Development,* ed. Hans P. Binswanger, Vernon W. Ruttan et al. Baltimore, Md., and London: Johns Hopkins University Press, 1978.

Fettig, Lyle P. "Adjusted Farm Tractor Prices for Quality Change, 1950–62." *J. Farm Econ.* 45(1963):599–611.

Griliches, Zvi. "Measuring Inputs in Agriculture: A Critical Survey." *J. Farm Econ.* 42(1960)1411–27.

Hayami, Yujiro, and Vernon W. Ruttan. *Agricultural Development: An International Perspective.* Baltimore, Md., and London: Johns Hopkins University Press, 1971.

Hicks, John R. *The Theory of Wages.* London: Macmillan & Co., 1932, 2nd ed. 1963.

Kennedy, Charles. "Induced Bias in Innovation and the Theory of Distribution." *Econ. J.,* 74(1964):541–7.

Kislev, Yoav, and Willis Peterson. "Relative Prices, Technology, and Farm Size." Dep. Agr. and Appl. Econ. Staff Pap. Ser. P80-11, University of Minnesota, May 1980.

Rasmussen, W. D. "Advances in American Agriculture: The Mechanical Tomato Harvester as a Case Study." *Technology and Culture* 9(1960):531–43.