Research, Technology and Farm Structure

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Abstract: *Public debate about the relationships among research, technology, and farm size is often fueled by a particular hypothesis, that public sector research supports the development of scale-biased technologies that lead to fewer and larger farms. The evidence suggests that it is the private sector that has dominated the development of scaled-biased, mainly mechanical farm technologies and that the public sector has concentrated on biological innovations, more likely to be scale neutral. Moreover, powerful macroeconomic and social forces, not simply the availability of new technologies, have driven change in the number and size distribution of American farms. The complexity of the determinants of farm structure make it unlikely that public research can guarantee the development of technologies that, by themselves, result in the preservation of small farms.*

Key Words and Phrases: *research, technology, farm size.*

The linkages among agricultural research, the generation of new technology, and changes in farm structure have long been of interest to economists. And, periodically, these relationships are the subject of politically-charged public debate, for example, in the 1970s over the development of the tomato harvester and more recently over the growth in large-scale hog production systems. In such cases, political interest is aroused because of the assertion of a particular hypothesis about the causal relationships among research, technology and farm structure; specifically, that public research supports the development of scale-biased technologies that lead to fewer and larger farms. This paper reviews the evidence provided by economic theory and analysis that bears on this hypothesis.

Defining Farm Structure

Economists can conceptualize any number of definitions or descriptions of the aggregate structure of the production agriculture industry, each one appropriate to understanding a different facet of the sector's economic behavior. In public debate, however, it is not always clear what is meant by farm structure, a difficulty compounded by the fact that farm structure is itself a proxy for some larger societal outcome: food security, quality of rural life, environmental soundness and the like.

Therefore, some acquaintance with the many definitions of structure can help differentiate among the arguments in public debate [for a full discussion see the annual U.S. Department of Agriculture (USDA) report on the family farm (Hoppe et al., p. 3)].

- *The distribution of sales, revenues and profits* within the farm sector can measure structure as a function of market presence, of economic significance.
- *Farming's importance as an income source* to households can indicate the degree to which agriculture is able to support families.
- *The degree of specialization* in output may provide an indicator of the existence of economies of scale or of dependence on one crop as well as motivate concern about environmental and economic sustainability.
- *Concentration of production* is again a measure of dependence on a relatively small number of large farms, a situation often perceived as disadvantaging small farms.
- *Ownership and control of resources* is an indicator of the extent to which a farm operation fits the traditional American view of a farmer as a self-sufficient, independent proprietor.
- *The farm's relationship to suppliers and to customers* may again reflect the operator's degree of independence but also responsiveness to market demands.
- *The number and size distribution* of farms is the most familiar descriptor of structure, although the picture may be different depending on whether size is measured in physical production units (acres, head of livestock) or revenues.

All the measures are useful in some context of understanding the evolution of the farm sector, and many have significance that is peculiar to the context of political argument.

For the remainder of this discussion, the number and size distribution of farms will serve as the short-hand definition of farm structure.

Forces That Drive Structural Change

To understand how technology affects farm structure, it is important to appreciate the full economic and societal context in which sectoral change occurs because technology is hardly the only—or even the most important—driver of structural adjustment in the farm sector. The relationships are complex and their relative significance varies with time, region and the specifics of the farm enterprise.

- *Off-farm income opportunities*, particularly since the end of World War II, have raised the price of labor (drawing it off farms), as well as made it possible to support part-time farming operations.

- *Demographic and lifestyle changes* continue to reflect shifting preferences for living in rural versus urban areas.
- *The relative prices of labor, land and capital* reflect their relative abundance or scarcity in the U.S. economy and play a major role in determining how they are combined in agricultural production.
- *The stock and quality of human capital* not only affects farmers' off-farm employment opportunities, but also the quality of farm managers and thus the sector's productivity and willingness and ability to adopt new technologies.
- *Public sector intervention* in agriculture has been extensive and has included not only support for research, education and extension, but the provision of direct subsidies for commodity production, subsidized credit, and technical assistance for natural resource management (to give some major examples of USDA programs). In addition, fiscal and monetary policies strongly affect agriculture through impacts on interest and exchange rates.

Evidence gained from the study of aggregate sectoral behavior and from individual case studies of technology adoption supports the notion that off-farm employment opportunities (in the form of jobs in higher-wage manufacturing industries) pulled labor off farms. The cost to hire on-farm labor escalated as a result, further raising its price relative to land, an abundant factor in the United States, and thereby inducing the development of labor-saving, land-using technology. This reading of the record suggests that conditions in the general economy as well as the factor endowment of the United States have determined parameters for structural change in the farm sector, and technology development has largely responded to these fundamentals (Fuglie at al., p. 5).

Technology's Effect on Farm Structure

Technologies may exhibit characteristics that can have an effect on farm structure. Following the Organization for Economic Cooperation and Development, technology is defined as "a stock of available techniques or a state of knowledge concerning the relationship between inputs and a given physical output" (p. 17). The best recognized aspect of a technology is the presence of scale bias, which means that a technology is more likely to be adopted by large production units because it requires a large initial investment, and the more units of output over which to spread this expenditure, the lower the per unit cost, the source of economies of scale. Scale-neutral technologies, on the other hand, operate as effectively on small farms as large, requiring no initial investment prohibitive for small output volumes. Technologies also vary in the intensity of use of the factors of production. Generally, technologies tend to use more of relatively abundant factors and less of the relatively scarce, a result predicted by the induced innovation hypothesis (Fuglie et al., p. 5). In the United States, land is relatively abundant, implying that technologies are likely to be developed to respond by conserving on the use of labor, the relatively scarce factor. Of course, in other places in the world, where factor endowments are different, farming looks very different and technologies peculiar to those situations have evolved. That is why U.S. and Canadian wheat farms operate in a very different manner from those in Belgium, for example.

Regardless of the characteristics of particular technologies, however, the process of adoption exhibits the same dynamics. Often called the agricultural "treadmill," the adoption process is initiated when the first farmers begin to use the new technology, then take advantage of the lower unit costs of production and expand output. These early adopters can expand their output without a significant impact on aggregate supply, so they enjoy higher sales without depressing market prices. But, as more and more farmers adopt the innovation and expand output, aggregate supply increases, lowering prices. The lagging farmers must adopt simply to avoid further losses. For the structure issue, it is important to know whether there is a pattern of adoption by farm size because it is the early adopters who are most likely to survive. The historical record shows no clear result. Large farms are not always the early adopters, although it does seem to be true that small farms tend to lag in adoption. However, in the case of scale-biased technologies, large farms would clearly be expected to adopt before the relatively disadvantaged smaller farms.

Generating Agricultural Technology

There is a simple story about the generation of farm technology in the United States that says the public sector has historically focused on biological innovations, which tend to be scale-neutral, and the private sector has dominated mechanical technologies, which tend to show scale bias. This interpretation of the record, then, would not support the notion that public sector research has driven the evolution toward a sector of very few, large commercial farms. However, real life is more complicated than the simple story would suggest.

Before examining a real-life example to illustrate the interplay of public and private agricultural research, it is worth an aside to note the motivation of private agricultural research investment. The private sector is interested in capturing the value of an innovation, that is, in being able to recover in the selling price the cost of the technology's development as well as some portion of its worth in use. So, while the private sector has dominated the development of mechanical technologies, it is not because they tend to show scale bias, but rather because the value of a tractor, for example, can be recovered in its selling price, thus providing compensation to its developers. Not all innovations demonstrate such appropriability, however. Better seed can be sold, but some of its value lies in the fact that the plants grown can themselves be used as a source of seed for the next year, meaning that the full value of the original seed is not likely to be captured by the seller.

To an even greater degree, the value of an innovation not embodied in physical technology is inappropriable. For example, knowledge about optimal planting dates can be used by its discoverer, but he or she may have difficulty concealing that information from competitors and in extracting payment for use of the knowledge. This lack of appropriability explains why public sector research should be directed toward such "public goods," those in which the private sector has no interest but which, if available, would benefit farmers (Fuglie et al., p. 7). Basic research is perhaps the best-known example of such a public good.

Development and Adoption of the Cotton Harvester

In the more complicated real world, the example of the mechanical cotton harvester is instructive in understanding the respective roles of the public and private sector in technology development and also in appreciating that the availability of technology is but one factor that drives adoption and structural change. The skeleton of the cotton harvester story is this: that off-farm opportunities for labor and changing wage rates encouraged the use of the mechanical cotton harvester, which was developed by the private sector. The harvester's adoption, in turn, brought an end to tenant farming and sharecropping in the South as the largely black population migrated to industrial jobs in the North and cotton farms grew in size as labor requirements diminished.

Many histories have been written about the cotton harvester, representing as it does a critical innovation in American agricultural and, perhaps more importantly, social history (see, for example, Fite and also Daniel). And the histories usually begin with the Rust brothers of Texas, who were among those who first turned their attention to the problem of developing a mechanical harvester for picking cotton, long recognized as the most arduous stoop labor in American farming. The Rusts' idea for a spindle-type machine did form the basis for the ultimate version of the harvester, but they were ambivalent about success, understanding that large-scale displacement of labor would necessarily follow adoption. A cotton harvester was available by the 1940s, but it was little used, and the Rusts themselves went bankrupt (Peterson and Kislev, p. 204).

The existence of the workable mechanical harvester was a necessary but not sufficient condition for its widespread adoption. While the private sector did indeed focus on the mechanical innovation (one with significant scale bias), the public sector paid attention to the cotton plant itself. A critical adjunct to mechanical harvesting was cotton plants that grew to uniform heights across the field and that ripened simultaneously (Fite, p. 197). Once such plants were developed, largely but not exclusively by the land grant universities of the South, it is true that any size farm could use them, but such plants were most valuable to those with a mechanical harvester. Still, even with the successful amalgamation of harvester and amenable cotton plant, adoption was not assured.

What slowed adoption of the harvester was the continued availability of relatively cheap labor to hand pick cotton. It was not until after World War II that migration from the rural south to northern industrial cities reduced the agricultural labor supply in cotton-growing areas and so put upward pressure on farm wages. As higher and higher prices had to be paid for cotton pickers, the harvester became relatively more attractive, leading to acceleration in the rate of its adoption in the 1950s (Fite, p. 204). As adoption proceeded, small farms in the South were disadvantaged because they could not afford the large initial purchase of the harvester. At the same time, cotton production was expanding to the West, increasing supply and pressuring prices downward when small farmers could least afford to lose revenue (Daniel, p. 251). According to USDA Economic Research Service demographer Calvin Beale, in 1949, there were 1.1 million cotton farms, averaging about 24 acres each, and only about six percent used the mechanical harvester. By 1974, there were 90,000 cotton farms, averaging 137 acres each, and all were mechanized; in the South, tenant farming and sharecropping, predominantly black farming patterns, had essentially disappeared. In 1997, there are 35,000 cotton farms, all mechanized, averaging 313 acres apiece.

The record does then show that adoption of the harvester and compatible cotton plants resulted in fewer and larger cotton farms. But a key question in exploring the role of the public sector is whether farm labor was *pushed* off the land by the harvester or whether it was *pulled* off by higher wage prospects in urban areas. An answer to that question would go a long way toward identifying a villain in this story, if there has to be one. It was not apparently until 1986 that economists made an attempt to investigate this issue empirically, when Peterson and Kislev estimated the source of shifts in the demand and supply of cotton-picking labor in mid-century. In their conception, adoption of the harvester would represent a decrease in demand for cotton picking labor (the push factor), while a decrease in the supply of labor would reflect the influence on migration of higher wages as a result of urban alternatives (the pull factor). In a two-equation econometric model, Peterson and Kislev tackle the "identification" problem in decomposing changes in the price of labor into that part attributable to supply and demand shifts. In their results, 80 percent of the reduction in the cotton-picking labor force was attributable to the pull of higher off-farm wages and 20 percent to the push of the adoption of the mechanical harvester.

The cotton harvester history demonstrates two important points about the linkages among research, technology and farm structure. First, the simple story about the public sector concentration on scale-neutral biological innovations may well be true, but the possibility exists, at least in some circumstances, of a synergistic relationship with complementary scale-biased technologies developed by the private sector. Second, the availability of a technological innovation may be a necessary but not sufficient condition for adoption. Powerful macroeconomic and social forces affect the economic context in critical ways, especially through influence on relative prices of land, labor and capital that dictate the conditions of profitable adoption, as Peterson and Kislev's findings demonstrate.

Size Bias in Technologies

In evaluating public sector responsibilities for agricultural research, however, many may find it inadequate to say simply that publicly-developed technologies have been scale neutral. What about the possibilities of generating technologies that are positively biased toward smaller size operating units? Economists have a hard time thinking about this kind of "reverse" scale bias, as there is no symmetry with the concept of economies of scale that underpins the large farm advantage. Instead, it seems that characteristics of small farms other than size per se would matter most in considering whether an affirmative effort to develop appropriate technologies is feasible. Then, the question becomes: what is a small farm and what are its important characteristics?

There are several statutory definitions of a "small" farm that provide a useful starting point. One in particular defines as "small" farms with annual sales of less than $20,000 (see Steele and Perry). The farms in this sales category control 18 percent of all farm land, account for 41 percent of the sector's net worth, and have low debt-to-asset ratios. These farms account for one-third of the entire sector's sales of beef, hogs and sheep. Farming is not the principal occupation for half of these operators. Collateral surveys also show that these operators have different views than do full-time farmers with respect to the importance of passing on the farm to heirs and valuation of the rural lifestyle. But this group of small farms is not as homogenous as statistical averages tend to imply. Three-quarters of all minority operators run such small farms, operators who are often older than average and who may be retired (Hoppe, p. 4). Moreover, even though many share the characteristic of being livestock producers, there is tremendous variation in the types of crops grown from one geographic region to the next.

What technologies would work for this diverse group? There is little systematic evaluation of this question, although there are many anecdotal suggestions, such as advocacy of rotational grazing. Even among small farms there are significant differences in resource endowments and in attitudes and expectations about the farm business. It is not clear that there is any nationally-applicable strategy for technology development that would be meaningful across the spectrum, with the possible, important exception of furthering education to improve farm management skills. However, there may be technologies that can be identified on a regional basis to suit geography, climate and cultural tradition. And, of course, there may be no technology that enables small part-time farmers to become small full-time farmers with farm income sufficient to support a household.

Conclusion

The conclusion is that public research cannot guarantee any particular outcome in farm structure because of the mediation of powerful economic and social factors. "Reverse engineering," the attempt to introduce technologies to keep small farms viable, is not likely by itself to be successful. In the end, the most efficacious way to affect farm structure may be to adopt a variant of the European approach: simply transfer income to keep small farms in operation. Of course, the way this policy is currently implemented through the Common Agricultural Policy is highly distorting to international trade, but direct payments would be equally or more effective, more likely acceptable under liberalized trade rules, and also more transparent (Organization for Economic Cooperation and Development, p. 51).

There is much opportunity for economists to be involved in helping devise effective strategies to guide public investment in agricultural research. The guidelines of economic theory provide a good starting point (Fuglie et al., p. 7). Identifying the existence of spillovers, particularly from investments by individual states, can help pinpoint important federal opportunities. Consideration of market failure in the provision of research to support improvements in environmental quality and in public health and nutrition is also key, as is the need for social science research to support public sector resource allocation. Very difficult public management problems must be addressed in a politically-charged atmosphere. Economists can assist by trying to understand what motivates public concern about agricultural research and its impact on the food and agricultural system and to design public policy analysis that illuminates the issues of the day.

Notes

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