Apresentação

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Zvi Griliches foi um dos pioneiros no estudo do processo de difusão tecnológica. Não por acaso, a presente edição da *RBI* reproduz seu trabalho como um reconhecimento às suas ideias fundadoras para a economia da inovação tecnológica.[1] O mérito do estudo de Griliches foi explicar o padrão de difusão tecnológica por meio de um exemplo que não poderia ser mais apropriado: o padrão de difusão do milho híbrido entre diferentes regiões produtoras dos Estados Unidos a partir da década de 1930. O trabalho foi publicado, pela primeira vez, em 1957 na *Econometrica*. Em 1960 uma versão mais sintética, ilustrada e atualizada foi publicada na *Science*, a qual é reproduzida nesta edição da *RBI*.

Como explicado por Griliches, no início do século passado, foram desenvolvidas pesquisas para a hibridação de variedades de milho. Já a oferta em escala comercial de sementes de milho híbrido se deu a partir dos anos 1930. Nas décadas seguintes houve uma mudança significativa na utilização de sementes, passando-se de variedades de polinização aberta para sementes híbridas. Inicialmente o processo ocorreu no chamado *Corn Belt* – tradicional região produtora de milho nos Estados Unidos – e com o tempo, embora em diferentes velocidades, se espalhou para outras regiões produtoras do país. Por exemplo, em Iowa, estado localizado no coração do *Corn Belt*, os produtores

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1 Antes dele, Joseph Schumpeter, em *Teoria do desenvolvimento econômico*, já havia considerado que as inovações não são distribuídas uniformemente ao longo do tempo. Sua análise do ciclo econômico, depois retomada em outras obras, pode ser entendida como a origem do interesse no processo de difusão (STONEMAN, 2002).

iniciaram o plantio com sementes híbridas antes dos produtores de outras regiões e a taxa de utilização avançou mais rapidamente do que em outros estados.

A explicação para as diferentes taxas de utilização de sementes entre as regiões produtoras relacionava-se às distintas expectativas de lucratividade com a substituição das sementes. Mesmo com as diferenças verificadas no início da adoção e na velocidade em que os novos híbridos eram adotados entre as regiões, na maior parte dos casos havia um padrão geral de difusão, o qual, ao longo do tempo, poderia ser descrito graficamente em uma curva em formato "s". Isto é, com base na observação empírica, seria possível identificar um padrão regular no processo de difusão que poderia ser descrito a partir de três parâmetros: a data de início do processo da disponibilidade comercial (*origin*); a velocidade relativa (*slope*); e o nível final (*ceiling*).[2]

Como dito, o início do processo de difusão do milho híbrido ocorreu em momentos diferentes entre as regiões produtoras. Em razão da necessidade de adaptação das novas sementes às condições específicas de clima e solo, a adoção pelos produtores dependia da disponibilidade destas em volume suficiente para o plantio em escala comercial. Por se tratar de um insumo que requer adaptação para poder desenvolver seu potencial de produtividade, foram necessários esforços e estratégias de pesquisa, desenvolvimento e adaptação para a substituição das velhas sementes pelos novos híbridos.

Além da adaptação às especificidades locais, o que se relacionava às contribuições das diversas estações experimentais, a oferta de híbridos estava associada às expectativas de lucratividade dos produtores de sementes em relação aos mercados "bons" e "ruins" para as referidas sementes. Isso explica o porquê do início do processo de difusão em escala comercial ter ocorrido no *Corn Belt* em meados dos anos 1930 e somente na metade de década seguinte ter se expandido para áreas mais ao sul do país. Assim, a lucratividade que os produtores de sementes esperavam de uma região poderia ser explicada pelo tamanho de seu mercado de sementes e do custo de entrada nesta região.

Já a taxa de aceitação das novas sementes híbridas estaria, na avaliação de Griliches, relacionada às expectativas de lucratividade dos produtores agrícolas. Após a introdução de sementes em escala comercial, na maior parte dos casos não haveria problemas com a oferta de sementes. Nesta perspectiva, a taxa de aceitação pelos produtores agrícolas pode ser entendida como a velocidade relativa do pro-

2 Em 1980, mais de duas décadas após a primeira edição do artigo, a *Econometrica* publicou uma réplica na qual o autor reafirma sua escolha pela função logística com três parâmetros. Segundo ele, suas escolhas foram motivadas por critérios econométricos e não representam nenhuma lei invariante ou inerente ao comportamento de difusão.

cesso de difusão. A lucratividade esperada com o novo material seria associada ao maior potencial de produtividade por área plantada (em relação às variedades de polinização aberta), como também na importância do milho na rentabilidade da propriedade agrícola.

Dados de 1959 indicavam que praticamente todo o *Corn Belt* usava sementes de milho híbrido e que a taxa de utilização de sementes híbridas era significativa também em outras regiões do país. Nas áreas em que a produtividade da terra era menor, a perspectiva de lucratividade desestimulava investimentos em materiais genéticos superiores, o que explicava as menores taxas de utilização de sementes híbridas. Porém, segundo Griliches, os níveis de adoção não são constantes.[3] A introdução de híbridos mais produtivos, as melhorias no mercado de milho e a ampliação na área plantada com o cereal poderiam alterar o nível final de adoção.[4]

Para Griliches, embora na prática seja difícil distinguir variáveis econômicas e sociológicas, quando a análise é realizada comparando-se diferentes regiões produtoras em nível nacional e tendo por base o longo prazo, as variáveis econômicas são os principais determinantes do padrão de mudança tecnológica. Portanto, o padrão de difusão do milho híbrido nos Estados Unidos, a partir da década de 1930, poderia ser explicado em termos econômicos, pois estava relacionado às expectativas de lucro por parte dos produtores de sementes híbridas e dos agricultores.

O estudo pioneiro de Griliches, geralmente colocado ao lado do trabalho de Edwin Mansfield, abriu espaço para uma ampla tradição de modelos econômicos que procuravam explicar em bases mais adequadas os diversos elementos relacionados ao processo de difusão tecnológica. Os esforços de Griliches foram significativos para ampliar o poder da análise econômica convencional em importantes fenômenos do processo de mudança tecnológica, como por exemplo: análise de dados de patentes como fonte de informação econômica; mensuração dos retornos públicos e privados decorrentes das atividades de Pesquisa & Desenvolvimento (P&D); e análise dos transbordamentos tecnológicos decorrentes das atividades de P&D.[5] Vale destacar também a contribuição do autor para as discussões sobre o processo de inovação tecnológica na agricultura, o que o colocou ao lado de seu professor, Theodore Schultz, entre os precursores neste campo de estudo.

3 Griliches (1980) destaca que o nível final de adoção é uma função de variáveis econômicas que mudam ao longo do tempo.

4 Na década de 1960, quase todo o milho cultivado nos Estados Unidos era híbrido. De lá para cá, houve aumento no potencial de produtividade dos diferentes tipos de híbridos e, notadamente a partir dos anos 1990, um forte avanço no plantio de sementes de milho geneticamente modificadas (PARDEY et al., 2010).

5 Uma síntese das principais contribuições de Griliches pode ser encontrada em Diamond Jr. (2004) e Griliches (2000).

Em 1965, o autor foi laureado com a *John Bates Clark Medal*, importante distinção concedida pela *American Economic Association*.[6] Ao longo de sua vida, Griliches recebeu diversas outras homenagens em reconhecimento às suas atividades de pesquisa e ensino. Faleceu em 1999, aos 69 anos. Mesmo não tendo recebido o Prêmio Nobel, muitos acreditavam (e ainda acreditam) que seus estudos o credenciavam para isso. Afinal de contas, como o leitor poderá verificar na sequência, seu trabalho sobre difusão tecnológica acabou difundindo ideias sobre a mudança tecnológica em um momento em que pouca atenção era dada ao tema.

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6 A descrição da biografia do autor no "John Bates Clark Award", em 1965, pode ser obtida em: <http://www.aeaweb.org/PDF_files/Bios/Griliches_bio_1965.pdf>.

Hybrid Corn and the Economics of Innovation

Geographic differences in the use of hybrid corn are explained by differences in the profitability of that use.

Zvi Griliches

The idea that a cross between plants that are genetically unlike can produce a plant of greater vigor and yield than either of the parental lines dates back to Darwin and earlier. Serious research on hybrid corn, however, did not begin until the first years of this century, and the first application of research results on a substantial commercial scale was not begun until the early 1930's. During the last 25 years, the change from open pollination to hybrid seeds has spread rapidly through the Corn Belt, and from the Corn Belt to the rest of the nation. The pattern of diffusion of hybrid corn, however, has been characterized by marked geographic differences. As shown in Fig. 1, some regions began to use hybrid corn much earlier than others, and some regions, once the shift began, made the transition much more rapidly than others. For example, Iowa farmers began planting hybrid corn earlier than did Alabama farmers, and Iowa farmers increased their acreage in hybrid corn from 10 to 90 percent more rapidly than did Alabama farmers.

Although the explanation of area differences in the pattern of diffusion of hybrid corn constitutes the main contribution of the study reported here (*1*), it is worth drawing attention first to the striking similarity in the general pattern of diffusion of hybrid seed in the various areas. Almost everywhere the development followed an S-shaped growth curve. As illustrated in Fig. 1, the rate of change is slow at first, accelerating until it reaches its peak, at approximately the mid-point of development, and then slowing down again as the development approaches its final level (*2*). Interestingly enough, this pattern of development also applies to increases in the use of farm equipment—combines, corn pickers, pickup balers, and field forage harvesters, as illustrated in Fig. 2. Similar patterns occur in the use of new drugs by doctors and in the diffusion of other new items or ideas (*3*). Thus, the data on hybrid corn and other technical changes in U.S. agriculture support the general finding that the pattern of technical change is S-shaped.

Although the finding that technical change follows this pattern is not very surprising or new (*4*), it is very useful. It allows us to summarize large bodies of data on the basis of three major characteristics (parameters) of a diffusion pattern: the date of beginning (origin), relative speed (slope), and final level (ceiling). The interesting question then is, given this general S-shape, what determines the differences among areas in the origin, slope, and ceiling? Why were some areas ahead of others in first using hybrid corn? Why did hybrid corn spread faster in some areas than in others? Why did some areas reach higher levels of equilibrium than others?

Date of Availability

Although the *idea* of breeding hybrid corn as we know it today goes back at least to 1918, to D. F. Jones and the double cross, the dates at which superior hybrids actually became available in different areas varied widely. Hybrid corn was not a once-and-for-all innovation that could be adopted everywhere. Rather, it was an invention of a new method of innovating, a method of developing superior strains of corn for specific localities (*5*). The actual process of developing superior hybrids had to be carried out separately for each locality. It is important to remember this fact before one blames, for example, the southern farmers for being slow to plant hybrid corn. Although superior hybrids became available in the Corn Belt in the early 1930's, it was only in the middle of the 1940's that good hybrids began to appear in the South. Thus, the date for a given area on which commercial quantities of superior hybrid seed were first produced is one of the major determinants of the development in that area.

We can take the date on which an area began planting 10 percent of its corn acreage to hybrid corn as the date on which superior hybrids became available to farmers in commercial quantities. As shown in Fig. 3, different areas in the United States reached the 10-percent level on different dates. For example, this level was reached in 1936 in some parts of Iowa and in northern Illinois but was not reached until after 1948 in some parts of Alabama and Georgia. The usefulness of the 10-percent level as a measure of the commercial availability of hybrid corn seed is indicated by the very close correspondence between this and an alternative measure. From records of state yield tests and from other publications it is possible to determine in what year hybrids first outyielded open-pollinated varieties by a substantial margin in a given locality. The "10-percent" definition used in this study has a .93 Spearman rank correlation coefficient with the "technical" definition.

Area differences in date of first planting of hybrid corn can be explained in terms of differences in date of availability of hybrid corn seed. Area differences in date of availability, in turn, can be explained, in part, in terms of some simple economic factors. Innovators among the seed producers first entered those areas where the expected profits from the commercial production of hybrid corn seed were largest. They entered the "good" areas ahead of the "poor" ones. It is no accident that, though the major innovation occurred in Connecticut, commercial development began in the heart of the Corn Belt where the potential market—farmers who buy and plant corn seed—was largest. The profits that seed producers can expect to make in a given region depend upon the size of the market for corn seed in that region and the cost of entry in that region.

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Market Density and Cost of Entry

The close correlation for an area between the date of availability of hybrid corn seed and the market for corn seed may be seen by comparing Fig. 3 with two reasonable measures of the market. The first measure is the density of corn acreage in 1949, shown in Fig. 4; the second measure is the density of corn pickers in use on farms, shown in Fig. 5 (the second measure is the better index of the "goodness" of a corn area and provides the best simple outline of the Corn Belt). This correlation is also demonstrated by plotting the date of entry of hybrid-seed producers into an area, as measured by the date on which farmers devoted 10 percent of their corn acreage to hybrid corn, against the average market density of the area. As shown in Fig. 6 the lower the market density, the later the date of entry into a given area. The rank correlation is high (.7), and even higher (.9) if the Southeast is excluded from the computations. The Southeast is a special case. It was entered later because of the relative lateness of the research contributions by the region's experiment stations and the obstacles put in the way of private seed companies in that area. Moreover, when one gets down to a certain low level it does not really pay to discriminate between areas on the basis of their relative market densities, and other variables become more significant.

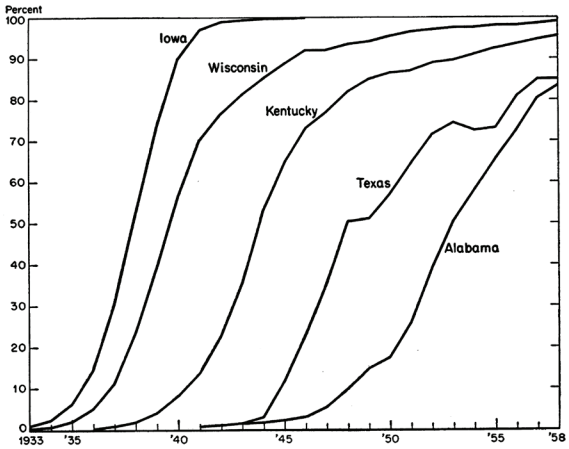


Fig. 1. Percentage of all corn acreage planted to hybrid seed. [*Agricultural Statistics*]

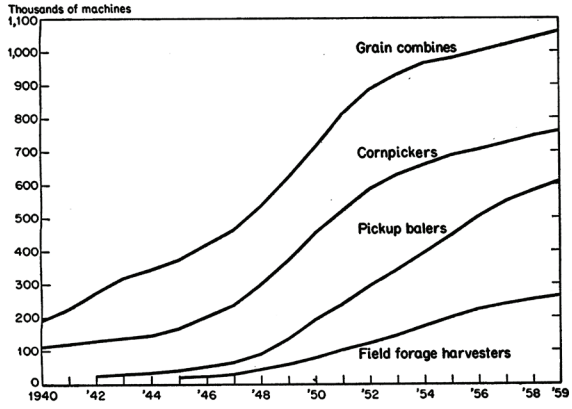


Fig. 2. Machines in use on farms in the United States, 1940–59. Note the resemblance to Fig. 1. [*U.S. Dept. Agr. Statist. Bull. No. 233* (1959)]

Deviations in the correlation between the spread of hybrid corn and the distribution of the market can be explained by the cost of entry factor. Cost of entry depends, among other things, on how different the area is from those already entered, and on whether experiment stations have already developed inbred lines and whole hybrids adaptable to the area. Study of Figs. 3, 4, and 5 shows first that the spread was much faster latitudinally than it was longitudinally. The reason, in part, is that an important factor determining the range of adaptability of a particular hybrid is the length of the growing season. To a large extent this is a function of latitude, and as one moves east or west the chances that the same hybrid will be adaptable to new areas are much higher than they are if one moves north or south. Nevertheless, the movement north seems to have been faster than the movement south. This is partly because of the larger markets in the north but is also a reflection of the special contributions of the Minnesota and Wisconsin agricultural experiment stations. They entered hybrid corn research very early in the game and contributed a great deal more than one would have expected from them just on the basis of the relative importance of corn in their states. Similarly, the contributions of Texas, Louisiana, and Florida stations came earlier and were relatively larger than those of the other stations in the South, which produced little of importance till the middle 1940's. This would explain to some extent why hybrid corn moved into the Southwest before it did into the Southeast. Moreover, quite a few of the Corn Belt inbreds and hybrids proved adaptable in the Southwest. It was more like the Corn Belt than was the Southeast, and it did not suffer to the same extent

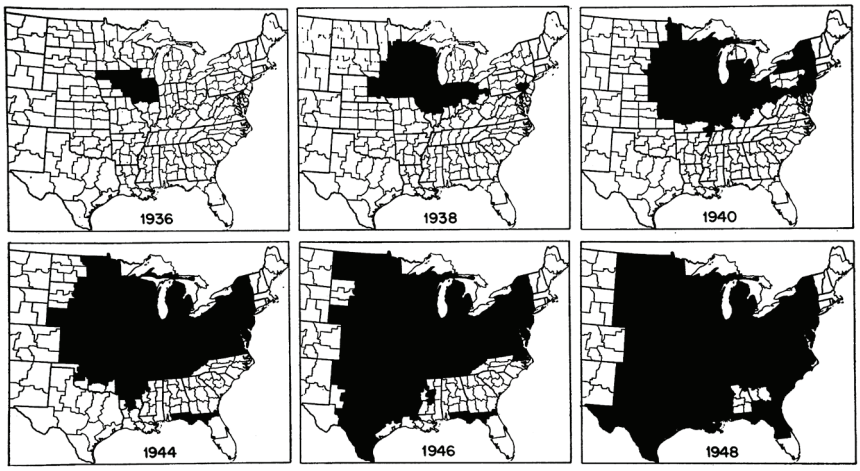


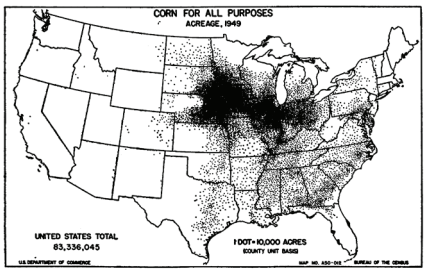
Fig. 3. The spread of hybrid corn: Areas that planted 10 or more percent of their corn acreage to hybrid seed in specified years.

from insect and disease problems that corn-breeders in the Southeast had to deal with (*6*).

Since cost factors in areas that are close together are likely to be similar, we may assume that entry into the neighborhood of an area makes entry into the area itself more likely, and thus we may use the earliest date of entry into any of the immediately neighboring areas as a proxy variable for the cost of entry into the given area. This variable and the measure of market density, taken together, explain to a large extent the variability in the dates on which hybrid corn was introduced in different parts of the country and support the statement that the innovators were influenced by considerations of profit, entering those areas first where the expected profits from innovation were highest.

Rates of Acceptance

The rate at which farmers in a region accepted hybrids, once hybrid corn became available, also varied from area to area. As shown in Fig. 7, this rate was highest in Iowa and the surrounding area and lowest in some of the areas of the Southeast and the Mississippi Delta states. The differences in the rates of acceptance are largely demand phenomena, not a result of different supply conditions. After the first few years, in most of the places and most of the time, the supply of seed was not the limiting factor. The rate of acceptance is taken to be the relative speed of the diffusion process—that is, it is the slope coefficient of the S-shaped curve (*7*). The measure is such that a value of 1.00 means that it takes 4 years for the acreage devoted to hybrid corn to rise from 12 to 88 percent, while a value of 0.5 implies that it would take 8 years, or



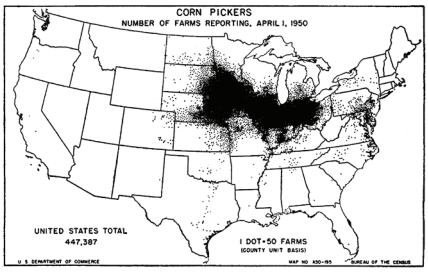


Fig. 4 (left). The market for hybrid seed. Corn acreage in 1949. Fig. 5 (right). Corn pickers on farms, 1950. This is a better index than corn acreage of the "goodness" of an area with respect to corn growing and provides the best single outline of the Corn Belt.

twice as long, for this same rise to occur.

The rate at which farmers accept a new technique depends, among other things, on the magnitude of the profit to be realized from the change-over. This hypothesis is based, first, on the general observation that the larger the stimulus the faster the reaction to it, and, second, on the fact that in an uncertain environment it takes a shorter time to find out that there is a difference, if that difference is large (*8*). Farmers doubted that this new hybrid corn was any good, and it took them some time to become convinced of its superiority. Individual farmers followed a development pattern of their own in shifting from open-pollinated to hybrid seed in planting their corn acreage (see Fig. 8). Almost no farmer planted 100 percent of his corn acreage to hybrid seed the first time he tried it (*9*).

Yield per Acre and Acres per Farm

The rate at which farmers shifted to hybrid corn depends, among other things, upon the profitability of such a shift. This in turn depends upon the absolute superiority of hybrids in corn yield in bushels per acre, and on the average number of acres per farm planted to corn.

It is widely accepted that hybrids out-

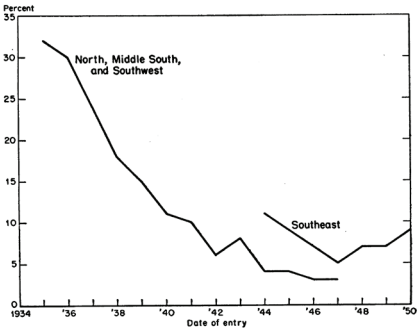


Fig. 6. Average market density by date of entry: Corn acres as a percentage of land in farms for crop-reporting districts reaching 10-percent use of hybrid seed corn in a specified year.

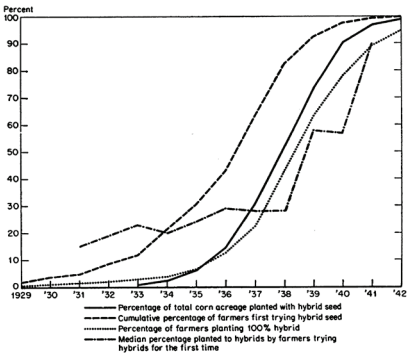


Fig. 8. The acceptance of hybrid corn in Iowa. Each farmer planted only a small fraction of his corn acreage to hybrid seed on his first trial. Only very late in the spread process did the "first timers" become bolder. [B. Ryan, *Rural Sociol.* **13**, 273 (1948); *Agricultural Statistics.*]

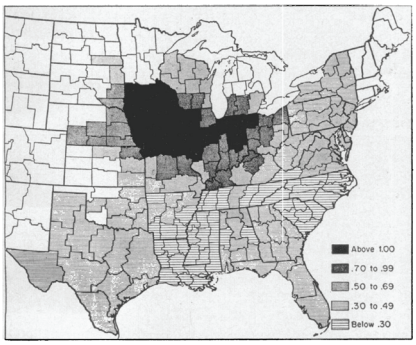


Fig. 7. Estimated rate of acceptance of hybrid corn by farmers in different parts of the country. A value of 1.00 means that it took 4 years for an area to increase its percentage of corn acres planted to hybrid seed from 12 to 88 percent. A value of 0.5 implies that it took twice as long, 8 years, to accomplish the same change.

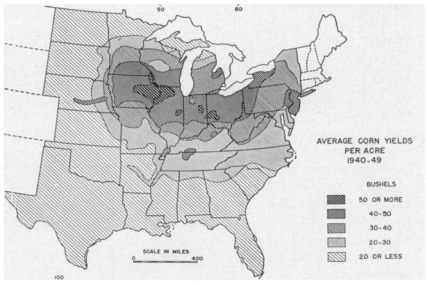


Fig. 9. The profitability of hybrid corn, as measured by average corn yields per acre, 1940–49. Since the superiority of hybrids was a constant percentage at different yield levels, differences in the *absolute* superiority of hybrids between areas are indicated by differences in the long-run levels of corn yields in the various areas. The period 1940–49 is neither strictly a pre- nor a post-hybrid period, but the differences in the levels of hybrid seed use in different areas during this period are unlikely to affect the relative ranking of the various regions with respect to their long-run corn-yield potentials. [From A. Grotewold, *Regional Changes in Corn Production in the U.S. from 1909 to 1949* (Chicago, 1955)]

yielded open-pollinated varieties by approximately 15 to 20 percent and that this *percentage* superiority did not vary much between different areas (*10*). Since similar percentage increases in yield imply different absolute increases in bushels per acre in areas where the previous yields were different, a good measure of the absolute superiority of hybrids over open-pollinated varities is given by the long-run level of corn yields in various areas. The distribution of corn yields in the United States, as shown in Fig. 9, shows strikingly close correlation with the distribution of rates of acceptance of hybrid corn, as shown in Fig. 7; The higher the yield, the higher the rate of acceptance.

Where the rate of acceptance fails to correlate with the yield per acre, the failure can be explained by taking into account the difference in the average number of acres of corn per farm (corn acreage per farm increasing as one moves from East to West), since what is important is not only the profitability per acre but also the profitability per farm. A large fraction of the variability between areas in the rate of acceptance of hybrid corn by farmers can be explained with the help of these two "profitability" variables (*11*).

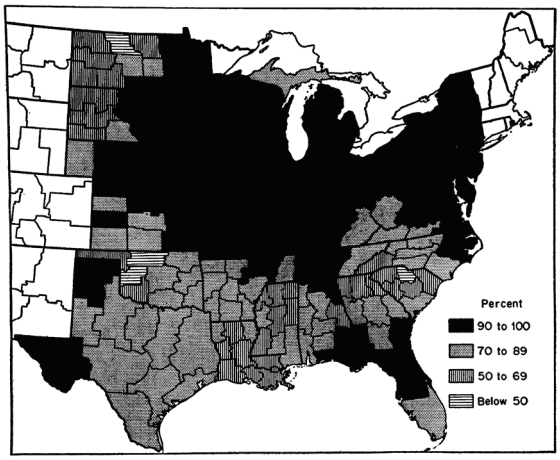


Fig. 10. Hybrid corn today (1959). Approximate percentage of total corn acreage planted to hybrid seed. State Agricultural Statisticians' release and unpublished Agricultural Marketing Service data.

Equilibrium Level

In an analysis of the use of hybrid corn in this country, one must consider, finally, differences in the equilibrium level reached—that is, differences in the fraction of the acreage which is ultimately devoted to hybrid seed. As shown in Fig. 10, different levels were found in different areas of the country. By 1959, close to 100 percent of the corn acreage in most of the Corn Belt and in its northern and eastern fringes was planted to hybrid seed. Substantially lower percentages were found only in the western fringes of the Corn Belt and in the deep South. In the South, the level is still changing, moving towards an equilibrium level of approximately 70 to 80 percent of the corn acreage planted to hybrid seed. The western parts of Nebraska, South Dakota, and Kansas have already reached their equilibrium level of approximately 30 to 60 percent. These are areas of very low and very variable yields, where the use of hybrid seed is unprofitable except on the better land or on land under irrigation.

Differences in the equilibrium level are explained by differences in the *average* profit to be realized from the shift to hybrid seed. In an area of high average profit no farmer faces a loss from the shift. In areas of low average profit a substantial proportion of the farmers face the possibility of having no return or even of sustaining a loss on their investment. The ceiling, or the fraction of the corn acreage that will ultimately be planted to hybrid seed, is not unique or constant. It will change with the introduction of better hybrids, with improvements in the market for corn, and with large changes in corn acreage. Nevertheless, for almost all of the areas except the very marginal ones, a constant ceiling fits the data well. Variation in these ceilings across the country can be explained in good part by the same two measures of profitability: the average absolute superiority of hybrids and the average number of acres per farm planted to corn.

Relation to Studies by Sociologists

It may prove useful to relate the results of this study to earlier work by sociologists in this area (*12*). In previous analyses of similar data it was mainly individual behavior that was investigated—that is, Who are the first and who are the last to adopt hybrid corn? —and an attempt was made to explain such behavior on the basis of differences in personality, education, economic status, and social environment. An attempt to use some of these variables (for example, level-of-living indexes) in explaining differences between states in the rate of acceptance of hybrid corn proved unsuccessful in this study.

It is my belief that in the long run, and when the country is taken as a whole, many of these variables either do not vary enough to be significant or tend to cancel themselves out, leaving the economic variables as the major determinants of the patterns of technological changes. This does not imply that the "sociological" variables are not important if one wants to know which *individual* will be first or last to adopt a particular technique, only that these factors do not vary much from area to area. Moreover, the distinction between "economic" and "sociological" variables is partly semantic, and a very difficult one to make in practice. Some of the variables used in this study—for example, yield of corn and corn acres per farm—are closely correlated with such variables as education, level-of-living, and socioeconomic status. It is very difficult to discriminate between the validity of the assertion that hybrids were accepted slowly because it was a "poor corn area" and the assertion that the

slow acceptance was due to "poor people." Poor people and poor corn are very closely correlated in the United States. Nevertheless, one may find a few areas where this is not so. Obviously, the slow acceptance of hybrids on the western fringes of the Corn Belt—in western Kansas, Nebraska, South Dakota, and North Dakota—does not reflect low economic status of the people but is the result of "economic factors" which make this a poor corn area.

Summary and an Implication

This study has increased our understanding of a body of data. What were originally puzzling and seemingly peculiar patterns in the data have been explained. The use of hybrid seed in an area depends, in part, upon the date at which superior hybrids become available. This date, in turn, depends upon the activities of seed producers guided by their expectations of profits, and upon the contributions of the various experimental stations. Thus, the South was late in getting hybrids because the market for seed was substantially poorer there than in other areas and because southern experiment stations produced few hybrids of importance until the middle 1940's. The use of hybrid seed in an area also depends upon the rate at which hybrids are accepted by farmers. This rate, in turn, depends upon the profit farmers expect to realize from the shift to hybrids. Thus, farmers in the Corn Belt accepted hybrids at a faster rate than farmers in the South because the absolute magnitude of profit was higher in the Corn Belt than in the South. Similarly, the fraction of acreage ultimately planted to hybrid seed depends upon expectations of profits to be realized from the change and the distribution of these expectations around their mean.

When uncertainty and the fact that the spread of knowledge is not instantaneous are taken into account, it appears that American seed producers and American farmers have behaved, on the whole, in a fashion consistent with the idea of profit maximization. Where the evidence appears to indicate the contrary, I predict that a closer examination of the relevant economic variables will show that the change was not as profitable as it appeared to be (*13*).

This study of hybrid corn has at least one interesting implication. Hybrid corn was an innovation which was more profitable in the "good" areas than in the "poor" areas. This, probably, is also a characteristic of many other innovations. Obviously, tractors contribute more on large than on small farms, and so forth. Hence, there may a tendency for technological change to accentuate regional disparities in levels of income and rates of growth. Moreover, this tendency is reinforced by the economics of the innovation process, which results in the new techniques being supplied to the "good" areas before they are supplied to the "poorer" areas, and also in the more rapid acceptance of these techniques in the "good" areas. A lag of this sort can by itself cause long-run regional differences in levels of income. The kinds of inventions we get, and the process by which they are distributed, may lead to aggravation of the already serious problem of regional differentials in levels of income and growth.

References and Notes

1. A more detailed and technical account of this study can be found in Z. Griliches, "Hybrid corn: An exploration in the economics of technological change," *Econometrica* (Oct. 1957). See also my "Research costs and social returns: Hybrid corn and related innovations," *Political Econ.* (Oct. 1958). This study was supported by the Social Science Research Council and the National Science Foundation.
2. In my article in *Econometrica* I show that the data fit the logistic growth curve very well. Unpublished data by small subdivisions —county and crop-reporting districts—give essentially the same picture, though the development is somewhat more irregular in the marginal corn areas.
3. See J. Coleman, E. Katz, H. Menzel, "The diffusion of an innovation among physicians," *Sociometry* (Dec. 1957).
4. See, for example, A. Lotka, *Elements of Physical Biology* (1925) and S. Kuznets, *Secular Movements in Production and Prices* (1930).
5. "Hybrid corn is the product of a controlled, systematic crossing of specially selected parental strains called 'inbred lines.' These inbred lines are developed by inbreeding, or self-pollinating, for a period of four or more years. Accompanying inbreeding is a rigid selection for the elimination of those inbreds carrying poor heredity, and which, for one reason or another, fail to meet the established standards" [N. P. Neal and A. M. Strommer, "Wisconsin Corn Hybrids," *Wisconsin Univ. Agr. Expt. Sta. Bull. No. 476* (Feb. 1948), p. 4]. "[The inbred lines] are of little value in themselves for they are inferior to open-pollinated varieties in vigor and yield. When two unrelated inbred lines are crossed, however, the vigor is restored. *Some* of these hybrids prove to be markedly superior to the original varieties. The development of hybrid corn, therefore, is a complicated process of continued self-pollination accompanied by selection of the most vigorous and otherwise desirable plants. These superior lines are then used in making hybrids" [R. W. Jugenheimer, "Hybrid Corn in Kansas," *Kansas Agr. Expt. Sta. Circ. No. 196* (Feb. 1939), pp. 3–4].
6. One can approximate a measure of the difference between the Corn Belt and some other areas with respect to the kind of hybrids they take by computing from lists of recommended hybrids in various areas and their pedigrees the percentage of all inbred lines accounted for by Corn Belt inbred lines. Such an index of "Cornbeltlines" had a correlation of .8 with the "date of origin" on the state level and of .7 with that on the crop-reporting-district level.
7. More exactly, the measure is the slope coefficient of the logistic growth curve as adjusted for ceiling differences. For an explanation of this measure see Z. Griliches, *Econometrica* (Oct. 1957).
8. This is analogous to sequential sampling. The "average sample number"—that is, the expected length of the experiment—will depend, among other things, inversely on the difference between the means of the two populations being sampled and directly on their variance.
9. That this is rational behavior in the face of uncertainty is intuitively obvious but difficult to prove. See H. A. Simon, *Models of Man* (New York, 1957).
10. Of course, hybrids differed from open-pollinated varieties not only in yield but also in improved stand, in uniformity, and in resistance to disease. However, there are no good quantitative measures of improvement in factors other than yield, and besides, most of the other improvements were correlated with the increases in yield.
11. Similar results were obtained from unpublished Agricultural Marketing Service data on the actual difference in the yield of hybrid and of open-pollinated varieties as a measure of the superiority of hybrids. Both the fit and the coefficients were very similar.
12. See, for example, B. Ryan and N. Gross, "Acceptance and Diffusion of Hybrid Corn Seed in Two Iowa Communities," *Iowa Agri. Expt. Sta. Research Bull. No. 372* (Jan. 1950), and "How Farm People Accept New Ideas," *Iowa State Coll. Spec. Rept. No. 15* (Nov. 1955).
13. That these findings are not restricted to hybrid corn has been confirmed by a recent study of the spread of a series of industrial innovations (diesel locomotives, continuous mining machines, and so on) within particular industries. It was found there that (i) the logistic growth curve summarized the data well, and (ii) most of the variability in the rate of acceptance of different innovations can be explained on the basis of the relative profit to be realized from the innovation and the size of the required initial investment. See E. Mansfield, "Technological change and the rate of imitation," a paper that was read at the 1959 winter meetings of the Econometric Society in Washington, D.C.