Factors explaining the diffusion of hybrid maize:
Evidence from Latin America and the Caribbean in support of
the life cycle theory of seed industry development

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Abstract:

Factors affecting the diffusion of hybrid maize are explored using a unique data set from 18 countries in Latin America and the Caribbean. Our findings not only validate the conventional profitability-based explanations of farmer adoption behavior, but also confirm the importance of supply-side factors, providing empirical support for the life cycle theory of seed industry development.

Introduction

In many Latin American and Caribbean countries, maize (*Zea Mays L.*) is the primary food staple and a mainstay of the rural economy. During the next 20 years, population and per capita income are projected to increase steadily in most of these countries, leading to increased demand for maize not only for direct human consumption, but also for use as animal feed. If domestic supplies of maize are to keep pace with future growth in demand, significant increases in production will have to occur.

Production increases in maize can be achieved through expansion in the area planted, yield gains, or both. Throughout most of Latin America and the Caribbean region, diminishing availability of arable land rules out the possibility of further expansion in the area planted to maize, suggesting that future production growth will depend mainly on yield gains made possible by the spread of productivity-enhancing technologies, including improved germplasm. In this context, identifying factors associated with the successful diffusion of hybrids and improved open-pollinated varieties (OPVs) is useful to policy makers interested in developing strategies to increase maize production.

Technology adoption decisions in developing countries have been extensively analyzed (for surveys of the adoption literature, see Feder et al., 1985; Rauyinar and Goode, 1992). Complementing the large amount of theoretical work that focuses on the process of technology adoption in general, numerous empirical case studies provide a wealth of information about the factors affecting the farm-level decision to adopt hybrid maize (for example, see Gerhart, 1975; Walker, 1981; CIMMYT, 1992; Byerlee et al., 1993; Smale et al., 1991, 1995; Kumar, 1994; Heisey et al. 1998). The common theme

emerging from this literature is that the decision to adopt hybrid maize is influenced by a complex and highly variable set of factors. Depending on the context, these can include demographic characteristics of the household (e.g., size, age and gender composition, wealth, education level), the expected profitability and/or perceived riskiness of the technology, farmers' consumption preferences, and the availability and cost of inputs, especially seed.

While the farm-level decision to adopt hybrid maize has been the focus of considerable research, much less work has been done at the aggregate industry level to identify factors that influence the diffusion of hybrid technology. In his pioneering study of the spread of hybrid maize in the United States, Griliches (1957) hypothesized that the uneven rate of diffusion could be linked to both demand and supply factors. Griliches determined that variability in the demand for hybrid maize in the United States is related to the additional profits that farmers expect to gain by switching from an OPV to a hybrid. Griliches also found that variability in the supply of hybrid maize is related to the revenue that seed suppliers expect to earn by entering the market, which in turn depends on the size of the market, marketing costs, product innovation costs, and the expected rate of acceptance.

More recently, Heisey et al. (1998) used cross sectional data to investigate how demand and supply factors influence the spread of hybrid maize in 32 developing countries. Heisey et al. found that at the aggregate (country) level, diffusion of hybrid maize depends partly on the expected profitability of the technology, which is influenced by technical, economic, and political factors. As well, they determined that the diffusion of hybrid maize is strongly influenced by the availability of high-quality seed, which

depends on characteristics of the seed market, the organization of the local seed industry, and the cost of research innovation, among other factors.

Following the approaches used by Griliches and by Heisey et al., we examine factors associated with the successful diffusion of hybrid maize in 18 countries of Latin America and the Caribbean region. Our model includes not only conventional demand-side factors that are expected to influence farmers' adoption decisions, but also supply-side factors that are expected to affect the incentives for firms to produce and sell hybrid seed.

Conceptual framework

Several authors have advanced life cycle theories of seed industry development in which national seed industries are described as evolving in a path dependent manner through successive stages of development (Douglas 1980, Pray and Ramaswami, 1991, Rusike 1995, Dowswell et al. 1996, Morris and Smale 1997, Morris et al 1998). Although the stages of development described by the various authors differ in their details, all of the life cycle theories posit that each stage tends to be associated with a characteristic, unique combination of technology, organizational arrangements, and institutional mechanisms.

In broad terms, four stages of development can be distinguished within the life cycle of a national seed industry:

Stage 1: Preindustrial Stage. Maize is produced for subsistence purposes, i.e., to satisfy household consumption requirements. Traditional varieties (also known as landraces) are grown using farm-saved seed or seed procured through farmer-to-farmer exchange. In the absence of formal research organizations, varietal improvement occurs as farmers replant seed from ears selected for their desirable traits. Seed information is

obtained through direct observation or from other farmers. Plant breeding and seed production are not commercial activities, so they are not subject to formal institutional control mechanisms.

Stage 2: Emergence Stage. Maize is still produced mainly for subsistence purposes, although surplus production may also be sold. Many farmers continue to grow traditional varieties, but some adopt improved OPVs, and a few even experiment with hybrids. Public research organizations begin conducting plant breeding research, and public agencies begin producing commercial seed. Seed production is still carried out mainly on the farm, although increasing numbers of farmers begin purchasing commercial seed. Public extension services play an active role in educating farmers about the advantages of improved germplasm and in disseminating varietal information. Since research and seed production activities are performed mainly by public organizations, the need for asserting and enforcing intellectual property rights is negligible.

Stage 3: Expansion Stage. Maize production becomes increasingly commercial, with more and more of the crop marketed. Most farmers have shifted to hybrids, although some continue to plant OPVs. Private firms conduct varietal improvement research and distribute commercial seed in direct competition with public agencies; very little seed is still produced on the farm. In addition to producing and selling seed, private companies also provide technical information. In the absence of effective plant varietal protection laws, firms rely mainly on trade secrets strategies to protect their intellectual property.

Stage 4: Maturity Stage. Maize production is completely commercial. Hybrids are the predominant technology, and most farmers purchase seed annually. Germplasm improvement research continues to be conducted by public breeding programs as well as

by private seed companies, but the two have become specialized, with the public sector focusing increasingly on basic research. Seed production has shifted completely to the private sector, and private companies have become the major source of technical information. Plant varietal protection laws are in place, and commercial legal systems function effectively at the international level to allow protection of intellectual property.

To date, few efforts have been made to test the validity of the life cycle theory of seed industry development. Similarly, little research has been done to explore the relationship between seed industry development and hybrid diffusion patterns. Empirical work in these areas is long overdue, especially in Latin America and the Caribbean region, where many governments have recently introduced policy reforms designed to improve the performance of the seed sector. In seeking to strengthen local seed production capacity and to improve the ability of public and private organizations to deliver improved seed to farmers, policy makers obviously gave an interest in understanding the factors that drive the development of the seed industry.

Model

According to the life cycle theory, seed industry development is associated with increasing levels of hybrid adoption. In our model we therefore use as the dependent variable the percent of national maize area that is planted to hybrids.

The full model is specified as follows:

Hybrid area   = f (seed price, seed price^2, NPC, sales, PVP, private, CIMMYT)

where:

  hybrid area   =   percent of national maize area planted to hybrids

  seed price   =   seed-to-grain price ratio

seed price^2 =   seed-to-grain price ratio squared

NPC   =   nominal protection coefficient for maize

sales   =   percent of maize production that is marketed

PVP   =   presence/absence of plant varietal protection laws

private   =   private sector percentage share of total seed sales

CIMMYT   =   percent of seed sold that contains CIMMYT germplasm.

Seven explanatory variables represent the economic, institutional, and policy factors that are expected to influence diffusion (see Table 1). These variables were chosen not only on the basis of conventional profitability-based explanations of farmer adoption behavior, but also to test the importance of supply-side factors as suggested by the life cycle theory.

Seed price: Seed price (expressed as the seed-to-grain price ratio to facilitate inter-country comparisons) is expected to affect the profitability of adopting hybrid maize. As with any purchased input, the higher the price, the lower the expected level of use. Thus the sign on this variable is expected to be negative.

Seed price^2: Seed price squared is included to allow the relationship between seed prices and hybrid adoption levels to vary according to the stage of seed industry development. Although economic theory suggests that higher seed prices can be expected to weaken demand for hybrids, seed prices tend to rise through time as the seed industry develops and as the area planted to hybrids increases. Heisey et al. (1998) explain this pattern by arguing that initially low seed prices are needed to encourage farmers to try hybrids, but once they have come to appreciate the benefits of the technology, they are willing to pay higher prices. Price increases occurring through time may also reflect

improvements in the quality of the varieties being developed, or simply marketing strategies by the seed industry. The sign on this variable is expected to be positive.

NPC: Nominal protection coefficients (NPCs) for maize were calculated to provide a rough measure of the level of policy protection afforded to the maize sector in each country. Although other measures, such as the effective protection coefficient (EPC) and the producer subsidy equivalent (PSE), provide a more comprehensive measure of the level of policy protection, the data needed to calculate these other measures were either unavailable, incomplete, or outdated. Since increased government protection for maize enhances the expected profitability of adopting hybrid maize seed, the sign on this variable is expected to be positive.

Sales: The percent of maize production that is marketed is included as another measure of seed industry development. As agriculture becomes more commercialized, farmers increasingly base input use decisions on profit maximization criteria, and purchased inputs rapidly replace those once non-traded (Pingali, 1997). In commercial production systems, input costs and expected returns take on increased importance in influencing technology adoption decisions. Further, from a seed industry perspective, where obvious market opportunities exist to increase returns by selling seed, better technologies will be developed and promoted. For both of these reasons, it is expected that the use of hybrids will be positively related to the degree of commercialization of the maize sector. Thus, the sign on this variable is expected to be positive.

PVP: Intellectual property rights are important to the development of the seed industry, because they can strengthen incentives for firms to invest in plant breeding research. Although hybrid maize technology has traditionally been protected through

control of the inbred lines needed to produce commercial seed, advances in technology have made it easier and cheaper for competitors to identify and replicate successful commercial hybrids. Without adequate intellectual property laws, it is becoming increasingly difficult to prevent free riders from appropriating benefits from research investments made by others. A dummy variable is used to indicate the existence or non-existence of plant variety protection (PVP) laws in each country. Since the existence of intellectual property laws presumably encourages increased investment in hybrid seed research, the sign on this variable is expected to be positive.

Private: According to the life cycle theory, as the seed industry matures, the private sector plays an increasingly prominent role in varietal research and seed production. As private firms become more prevalent, they compete for potential customers by stepping up their marketing efforts. Their efforts to develop product and brand awareness, trust, and customer loyalty stimulate further adoption of hybrid maize technologies. Private seed sales as a percent of total industry seed sales is used as a measure of private sector participation. The sign on this variable is expected to be positive.

CIMMYT: The availability of improved germplasm developed by public breeding programs helps to stimulate private-sector investment in plant breeding, because it is considerably less costly for private seed companies to develop new hybrids when public germplasm is freely available (López-Pereira, 1997). The International Maize and Wheat Improvement Center (CIMMYT) is the leading publicly funded maize breeding organization in the developing world. Since CIMMYT germplasm is freely available to private seed companies, one measure of the availability of publicly developed germplasm

is the percent of commercial seed sold that contains CIMMYT germplasm. The sign of this variable is expected to be positive.

Data

As part of an ongoing effort to document the impacts of international maize breeding research, CIMMYT periodically surveys organizations engaged in maize research and maize seed production activities. In 1996-97, staff of the CIMMYT Economics Program carried out a comprehensive survey of public and private maize seed organizations located throughout Latin America and the Caribbean region. Data collected through this survey, which involved interviews with approximately 175 organizations in 18 countries, were used to estimate the model. (Additional information about the scope and content of the survey appears in Kosarek, 1999.)

Results

Because the dependant variable is continuous but censored between zero and 100, the model was estimated using a tobit approach, which is based on a maximum-likelihood estimation procedure (MLE). For comparative purposes, the model was also estimated using the ordinary least squares method (OLS). Since only two observations of the dependent variable were at a limiting value, the OLS results are expected to be similar to the tobit (MLE) results.

Table 2 presents the estimated coefficients obtained using the two approaches, as well as the marginal effects of the explanatory variables calculated from the tobit results. The marginal effects measure the effects of one-unit changes in the value of the explanatory variables on the dependent variable, given the censoring of the dependent variable.

The results presented in Table 2 are noteworthy in three respects. First, there exists a high degree of correspondence between the tobit (MLE) and OLS estimated coefficients, as well as between the estimated tobit (MLE) coefficients and their marginal effects. Both of these results presumably stem from the limited degree of censoring of the dependent variable (only two observations at the limit).

Second, the significance of the estimated relationships is high. Based on the adjusted R^2 and the Wald test, the overall significance of the relationships seems acceptable. In terms of the estimated coefficients from the tobit (MLE) model, using a one-tailed test, seed sales by the private sector as a percent of total industry sales (*private*) is significant at the 10% level. All other variables are significant at the 1% level.

Third, the signs of the estimated coefficients on the explanatory variables are consistent with expectations. On the demand side, the level of hybrid adoption is positively associated with: (1) low seed-to-grain prices during initial stages of seed industry development, and (2) the existence of government protection for the maize sector. On the supply side, the level of hybrid adoption is positively associated with: (1) high seed-to-grain prices during later stages of seed industry development, (2) the degree of commercialization of the maize sector, (3) the percentage of total seed sales made by the private sector, (4) the percentage of seed sold that contains germplasm developed by public breeding programs, and (5) the presence of intellectual property rights laws.

Discussion

Our results suggest that at the aggregate (country) level, the diffusion of hybrid maize technology can be explained in terms of a combination of economic, institutional, and policy factors. Consistent with earlier findings reported by Griliches and Heisey et al., we

conclude that diffusion is influenced not only by demand-side factors that affect the incentives for farmers to adopt improved germplasm, but also by supply-side factors that affect the incentives for firms to produce and sell hybrid seed. In addition to validating conventional profitability-based explanations of farmer adoption behavior, our findings provide strong empirical support for the life cycle theory of seed industry development and confirm its usefulness in explaining the spread of hybrid maize in Latin American and Caribbean countries.

In terms of drawing policy implications, these results must be interpreted with care. The life cycle theory indicates that the diffusion of hybrid maize is influenced by a large number of interrelated and time-dependent factors, so not only the nature but especially the sequencing of policy interventions is likely to be important. One thing seems clear, however: If the hybrid diffusion process is to be accelerated, policy makers need to ensure an environment in which it is profitable not only for farmers to adopt improved germplasm, but also for the seed industry to produce and sell high-quality seed.

What policy options are available to achieve these two objectives? On the demand side, policy interventions to promote increased use of hybrid seed are relatively limited, since the profitability of adopting hybrids depends to a considerable extent on factors that are difficult for policy makers to control (e.g., agro-climatic conditions, basic factor endowments, access to global markets). In some countries, governments have attempted to stimulate technical change by increasing the profitability of maize production, either directly (by supporting producer prices) or indirectly (by restricting grain imports through quotas or tariffs), but in the long run such protectionist policies often turn out to be unsustainable because they impose an unacceptable fiscal burden. Experience suggests

that a more effective way to increase demand for hybrids is to invest in programs designed to educate farmers about the potential benefits of adopting improved seed. The role of the state in providing technical information is particularly important during the early stages of seed industry development, when the market for commercial seed is still poorly developed and private firms have little incentive to invest in extension activities.

On the supply side, policy measures needed to accelerate the diffusion of hybrid technology are more obvious. In order to foster the emergence of a flourishing seed industry, policy makers should consider steps to encourage the development and growth of private firms, improve the efficiency of the grain and seed marketing systems, and promote commercialization of the maize sector in general. In pursuing these objectives, timing is likely to be important, since the existence of an efficient grain marketing system (for example) in and of itself is unlikely to stimulate widespread uptake of hybrids if an unfavorable business climate continues to stifle the activities of private seed companies. In this context, legislation that protects firms' intellectual property rights may be needed to provide adequate incentives for private firms to invest in the seed sector. Finally, experience suggests that large firms operating in commercial marketing environments can more easily take advantage of potential economies of scale in varietal improvement research, so institutional arrangements that encourage specialization and permit a more efficient transfer of improved germplasm from public breeding institutions to the private sector are also likely to be important.

Table 1: Variable descriptions

	Variable Name	Measurement	Expected sign
Dependent variable			
Adoption of hybrid maize seed	Hybrid area	area planted to hybrids as a percent of national maize area	
Independent variables			
Maize seed price (1)	Seed price	seed-to-grain price ratio of the most commonly sold type of seed	–
Maize seed price (2)	Seed price^2	the variable *seed price* squared	+
Government support policies for maize	NPC	nominal protection coefficient for maize	+
Commercialization of maize production	Market	the percent of total maize production that is marketed	+
Legislation protecting intellectual property	PVP	presence/absence of plant varietal protection laws (1 = yes, 0 = no)	+
Prominence of the private seed industry	Private	the percent of total industry seed sales by the private sector	+
Cost of research innovation	CIMMYT	the percent of all seed sold containing CIMMYT germplasm	+

Table 2: Tobit results, OLS comparisons, and marginal effects

	Tobit (MLE)	OLS	Marginal effects
constant	-340.04	-316.87	-339.682
	(-7.563)	(-6.090)	
seed price	-7.53	-7.074	-7.521
	(-5.992)	(-4.684)	
seed price^2	0.218	0.201	0.2176
	(5.710)	(4.482)	
NPC	0.8948	0.864	0.894
	(5.648)	(4.492)	
market	2.293	2.218	2.290
	(8.205)	(6.549)	
PVP	33.15	30.67	33.115
	(3.548)	(2.739)	
private	0.29	0.319	0.289
	(1.522)[a]	(1.359)[a]	
CIMMYT	1.291	1.095	1.29
	(3.795)	(2.863)	

Wald test: Chi-squared (Tobit) 112.51

Adjusted R-squared (OLS) 0.801

σ = 10.04

Proportion of the sample between the limits = 88.9

a Significant at the 0.10 level. All others, significant at the .01 level.

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