E C O N O M I C S

Working Paper 97-05

Organization and Performance of National Maize Seed Industries: A New Institutionalist Perspective

Michael L. Morris and Melinda Smale

CIMMYT

Organization and Performance of National Maize Seed Industries: A New Institutionalist Perspective

Michael L. Morris and Melinda Smale

Introduction

Thirty years after the spread of semidwarf varieties of rice and wheat dramatically boosted production of these two crops in many developing countries, a similar germplasm-led Green Revolution in maize has yet to occur. Modern maize hybrids and associated crop management practices have the potential to bring about significant productivity increases, yet the impact of seed-fertilizer technologies has been relatively disappointing in maize-based cropping systems. Adoption has been extensive in some areas, but improved germplasm has yet to benefit vast regions in the developing world, especially in sub-Saharan Africa and Latin America where maize is the leading staple and a mainstay of the rural economy.

The absence of a broad-based Green Revolution in maize is puzzling in view of what has happened in industrialized countries, where hybrids have been extensively adopted and where use of purchased inputs on maize is high. Efforts to explain the disappointing record of maize in developing countries are focusing increasingly on the seed industry. The distinctive biological properties of maize plants (in particular, their propensity to cross-pollinate) make it difficult for farmers to maintain the genetic purity of maize seed saved from their own harvest; as a result, if farmers wish to grow a particular commercial variety or hybrid, they must replace their seed on an annual basis.[1] Maize growers thus are dependent on external sources of seed in a way that growers of self-pollinating crops such as rice and wheat are not.

In many developing countries in which maize is an important crop, governments have invested heavily in maize varietal research, seed production, and seed distribution activities. Judging from the prominent role frequently assigned to public organizations, the view prevailing among policy makers seems to be that these activities are too important to be entrusted to the private sector. Yet by and large, the performance of public seed organizations has been disappointing. Plagued by the problems commonly associated with public-sector organizations – inadequate funding, shortages of trained personnel, inflexible management structures, lack of accountability – most state seed organizations have consistently failed to live up to expectations. Clearly past approaches have not worked very well and will have to be modified.

For better or for worse, the need to rethink maize research and development strategies comes at a time when public support to agriculture is declining. Forced to re-evaluate the desirability of continuing long-standing government spending programs, policy makers in many developing countries are choosing to relieve pressure on overburdened government

[1] Not all farmers are interested in preserving the genetic purity of commercial varieties and hybrids, however; some deliberately alter the genetic composition of commercial cultivars by selecting for desirable traits.

budgets by encouraging the privatization of selected activities traditionally carried out by public agencies. Plant breeding and seed production, which offer obvious opportunities for commercial gain, are frequently among the first activities targeted for privatization.

Judging from the experience of many industrialized countries, the maize seed industry indeed appears to be a suitable candidate for privatization. In the United States, Canada, and Western Europe, maize varietal development, seed production, and seed distribution are now performed largely by private firms. The industry is populated by large transnational corporations with familiar names: Pioneer, Novartis, Cargill, DeKalb, Limagrain, Monsanto. The maize seed divisions of these corporations have grown and prospered because they have been able to identify the germplasm needs of commercial farmers, develop hybrids that successfully meet those needs, produce high-quality seed, and distribute that seed at attractive prices. Their success has heightened the perception that private companies are well equipped to handle varietal development and seed production activities and has fueled a ground-swell of support for privatizing these activities in developing countries.

Not everybody is comfortable with the idea of a global maize seed industry consisting exclusively of private companies, however. Some observers argue that privatization poses a risk because the quest for profits could lead seed companies to act in ways that are not necessarily in the best interest of all producers and consumers. Private companies clearly have economic incentives to serve the needs of large-scale commercial producers who represent a potentially lucrative market for seed, but they probably have much less reason to address the needs of small-scale subsistence farmers who may be unable or unwilling to purchase seed on a regular basis.

Considering the disappointing performance of many public-sector seed organizations, policy makers are clearly justified in encouraging private companies and nongovernmental organizations (NGOs) to play a greater role. Mandating that public organizations withdraw completely from the maize seed industry would probably not be desirable, however, because private firms are unlikely to engage in activities that offer limited profit opportunities, including germplasm collection and conservation, as well as many types of basic research. Furthermore, private seed companies might neglect small-scale farmers in marginal production environments who, because of their dispersed distribution, special germplasm requirements, and modest purchasing power, do not represent an attractive market. Thus, increased privatization will have to be encouraged in ways that ensure that the needs of the widest possible range of producers and consumers are addressed. Privatization of the maize seed industry will be a failure if the old state monopolies are simply replaced by new private ones.

This paper seeks to contribute to the seed industry policy debate by proposing a conceptual framework that can be used to analyze the organization and performance of national maize seed industries.[2] The discussion proceeds in four stages. First, we review what industrial organization theory has to say about the suitability of various types of organizations for

[2] For a comprehensive discussion of the maize seed industry, which covers the issues raised in the preceding paragraphs and other pertinent issues, see Morris (1998a).

carrying out different production and distribution activities. Second, we describe several important attributes of seed that make it different from most other goods. Third, we summarize the findings of several recent country case studies suggesting that as national maize seed industries develop, they pass through predictable stages of growth that can be characterized as an industrial life-cycle. Finally, we discuss the policy implications of these findings, paying particular attention to the evolving roles of the organizational players that make up the industry.

Industrial Organization Theory and the Maize Seed Industry

What would an "ideal" maize seed industry look like, and how would it function? Neoclassical economics, institutional economics, and the theory of public choice provide some useful insights for understanding the forces that condition the behavior of individuals and firms in responding to economic and other incentives. These insights can be particularly valuable in helping to identify forms of industrial organization and supporting institutional arrangements likely to be associated with good performance in the seed industry. Several of these insights are briefly reviewed in this section, with an eye toward building an integrated conceptual framework designed to shed light on the forces that underlie the growth and evolution of national maize seed industries.

The Neoclassical Paradigm

According to neoclassical economic theory, the most efficient form of industrial organization is the competitive market made up of large numbers of economic agents (individuals or firms). These economic agents seek to maximize their welfare by engaging in production, consumption, and exchange activities. Voluntary transactions serve to equilibrate supply and demand for goods and services at market-clearing prices that lie close to the low points on the industry's long-term average cost curves. Market participants are assumed to have full and free access to information and are able to adjust their bid and offer prices instantly and without cost. Guided by an invisible hand, the market clears, the most efficient technology prevails, and excess profits are eliminated. Divergences from this idealized scenario are explained in terms of "market failure." Whenever real-world performance fails to conform to the predictions of the theory, neoclassical economists explain that the efficient functioning of the market economy is being impeded by exceptional circumstances (e.g., externalities, natural or contrived monopolies, wage and price stickiness). The fact that "exceptional" circumstances often arise does not so much negate the validity of the theory as inhibit its normal operation.

Institutionalist Modifications

Despite its usefulness for analyzing many economic phenomena, the neoclassical paradigm suffers from a major problem: the idealized market economy depicted in the textbooks often fails to correspond to the messy reality of everyday life. After it became clear that the discrepancy between neoclassical theory and reality is too large to be ignored, attempts were made to modify the theory to increase its relevance for applied analysis. One particularly influential source of modifications has been a group of economists who have focused on the role played by institutions (formal and informal "rules of the game") in

shaping economic activity. Previously, institutional matters had largely been relegated to a black box; even when institutions had been acknowledged, they had rarely been integrated into analytical models (Bardhan 1989).

Institutional economists recognize that the real world is not inhabited by rational, all-knowing, self-interested decision makers and that people do not engage in instantaneous, costless transactions leading to efficient, utility-maximizing market outcomes. Instead of resembling the predictable, stylized actions depicted by neoclassical theory, people's actions are shaped by a wide range of factors that influence the way they absorb and evaluate information, take decisions, and act upon those decisions. In the institutionalist universe, economic agents still seek to maximize utility, but the ability (or in some cases the desire) to pursue this goal now is compromised. As a result, economic systems often generate outcomes different from those predicted by neoclassical theory.

To appreciate the importance of the factors that affect human behavior and to understand their relevance for the study of maize seed industries, it is useful briefly to review the work of several seminal thinkers in the field of institutional economics.

Ronald Coase (1960) developed a framework for analyzing the organization and performance of industries that revolved around the concept of *transactions costs*. Coase argued that firms and markets represent alternative ways of organizing production, and that firms replace markets when the cost of conducting transactions through the firm is lower than the cost of conducting them through the market. According to Coase, what firms decide to buy, produce, and sell is determined by the relative size of the cost of administering transactions internally versus the cost of conducting them through the market. If the cost of administering transactions internally is lower than the cost of conducting them through the market, the firm will internalize the transactions (this process is known as *vertical integration*). But if the costs of conducting transactions through the market is lower than the costs of administering them internally, the firm will engage in buying and selling activities.

Coase's pioneering work on transactions costs was modified and extended by Oliver Williamson (1975, 1985). Williamson added a behavioralist dimension designed to take into account the influential role played by individuals in determining the performance of economic systems. According to Williamson, in order to understand economic systems, it is necessary to recognize two distinguishing characteristics of the people who populate them. First, people are *boundedly rational*, meaning that there are limits to the amount of information they can assimilate and process. This implies that they can never know everything about a transaction. Second, people are *opportunistic*, meaning that they will act in ways that enhance their self-interest (e.g., they will misrepresent the quality of their products and will renege on contracts when they believe it is in their interest to do so). These two characteristics of human behavior have important implications for the performance of economic systems. Because of bounded rationality, all contracts are necessarily incomplete. Because of opportunism, all contracts are subject to rupture. Taken together, this means that when individuals acquire new information, they will tend to reassess their contracts and possibly break them, resulting in increased transactions costs as both parties continuously re-adjust to the succession of broken contracts. Williamson argues

that in order to lower transactions costs over the long term, potential parties to transactions develop institutional supports (rituals, customs, and/or standard operating procedures) that enable them to economize on bounded rationality while securing protection against the hazards of opportunism.

Whereas Coase concentrated on two alternative ways of organizing economic production (markets and firms), Williamson extended the typology, positing that four generic forms exist for organizing economic activity: (1) markets, (2) hierarchies, (3) government bureaus, and (4) "hybrids" (e.g., strategic alliances, joint ventures, licensing agreements). These four forms differ in their incentive structures, administrative costs, ability to adapt to disturbances, and legal requirements, making them differentially suited for different types of transactions. According to Williamson, institutional arrangements evolve that minimize transformation and transactions costs. This evolution can occur in several ways. Most often, inefficient forms of organization are eliminated through market competition. Less commonly, inefficient forms of organization are deliberately replaced in the wake of careful analysis and planning.

Douglass North (1990) offered a slightly different interpretation of the process driving institutional change. North started with three basic assumptions that are quite similar to Williamson's ideas about bounded rationality and opportunism. First, individuals are concerned with maximizing their own welfare; when information costs are high, individuals stand to gain by disobeying rules that others are expected to obey. Second, it is costly for individuals to specify and enforce rules when information is imperfect. Third, socially conditioned belief systems enable individuals to economize on information costs while forming judgments about the fairness and legitimacy of alternative institutional arrangements (i.e., their actions are often guided by ideology). Starting with these three basic assumptions, North explored the process of institutional change by focusing his attention on economic systems experiencing periods of disequilibrium, including systems undergoing development. North observed that transactions costs appear to increase during periods of disequilibrium because of increasing possibilities for opportunistic behavior. Against this background, markets and institutions change over time because people acquire knowledge and skills that lead to revised evaluations of their opportunities. This induces them to alter the formal rules and informal constraints governing behavior, so that new ways of organizing economic activity eventually emerge. The process is not deterministic, however. If the overall institutional framework provides incentives that encourage people to engage in productive activities, then the economy will be driven along a path leading to economic progress. But if the institutional framework provides incentives that encourage people to engage in unproductive activities, then the economy will stagnate. As economic development proceeds, information costs proliferate, and increasingly complex institutions are needed to hold down contract enforcement costs.

The Marxist Perspective

In contrast to the institutional economists, who describe industrial change as being driven by the desire to reduce costs, Marxian economists offer a somewhat different explanation. The Marxian view was expounded by Jack Kloppenburg (1988) in his interpretation of the process of industrial evolution in terms of fundamental historical processes associated with the political economy of capitalism. According to Kloppenburg, the two key processes

driving organizational change in the seed industry are *primitive accumulation* (the separation of the worker from the means of production) and *commodification* (the extension of the commodity form to seed).

Kloppenburg analyzed the evolution of the maize seed industry in the United States. He argued that as long as open pollinated varieties (OPVs) remained the dominant technology, farmers retained the ability to save seed from their own harvest to replant the following season. This left effective control over the means of production in the hands of direct producers, and rent-seeking firms had no incentive to enter into the seed industry. In order to create economic incentives (which are needed to pave the way for the expansion of capitalism), it was necessary for farming to be converted from a largely self-sufficient production process into one in which purchased inputs account for the bulk of the resources employed. In the Marxian view, this transformation can be seen as a process of primitive accumulation in which the farmer is progressively separated from the means of agricultural production, including seed. According to Kloppenburg, in the U.S. maize seed industry the key development in this process was the commodification of seed, which was made possible by the introduction of hybrid technology and the extension of property rights to germplasm. These developments dispossessed farmers from control over the means of production by preventing them from autonomously reproducing seed for their own use.

In Kloppenburg's view, the U.S. maize seed industry evolved to support a capitalist mode of production (agribusiness) characterized by the existence of a class of direct producers who were dispossessed of the means of production. This process affected not only the seed industry, but agricultural science itself. Reviewing the history of maize research in the United States, Kloppenburg argued that over time a social division of labor occurred that progressively subordinated public research to serve the needs of private industry. To see this, we need only to look at maize breeding research: in stark contrast to the early part of the century, when virtually all commercial OPVs and hybrids were developed and released out of the public sector, today public research programs no longer release commercial materials.

Further Institutionalist Modifications

The pathbreaking institutionalist work of Coase, Williamson, and North has been complemented in recent years by ideas associated with a school of thought generally referred to as the "new institutional economics" (NIE). The somewhat disparate literature of the NIE has concentrated particularly on issues related to interest group formation, collective action, organization theory, bounded rationality, transactions costs, and the relationship between technological change and institutional change. Nabli and Nugent (1989a, 1989b) aptly describe the subject matter of NIE — institutions and their determinants — as the "very battleground" of the neoclassical and Marxist paradigms.

Many NIE concepts are derived from ideas advanced by earlier institutionalists, such as the idea that the main force driving organizational change is the drive to save on transactions costs. Schmid (1987) and others build on this idea, arguing that the size and distribution of transactions costs are influenced not only by market structural conditions, availability of information, and technology, but also to a considerable extent by the characteristics of products themselves (see Piciotto 1995; Ostrom, Schroeder, and Wynne 1993; Ostrom,

Gardner, and Walker 1994). NIE proponents point out that traditional approaches to policy analysis frequently ignore important differences between types of goods.

One of the principal arguments made by NIE proponents is that when organizational options are described using a simple *public* versus *private* dichotomy, policy analysis is severely constrained, and the range of diagnostic/prescriptive options is reduced to just two: "market failure/government must intervene" and "state failure/government must privatize" (Ostrom, Schroeder, and Wynne 1993; Ostrom, Gardner, and Walker 1994; Klitgaard 1991). According to the NIE school, the *public* versus *private* dichotomy is inadequate because forms of economic organization are myriad and many institutional configurations cannot be described accurately using such a simplistic classification.

Recent theoretical work has expanded the traditional institutionalist framework. Ostrom (1995) and others describe arrangements under which participants voluntarily agree to cooperate in order to achieve some common objective, without any expectation of remuneration. Because voluntary cooperation involves neither administrative fiat nor negotiated exchange, this approach to organizing economic activity cannot readily be described using the conventional categories of state (*public*) and market (*private*). A similar approach appears in the work of Gerrard (1995), who proposes an alternative "pure type" classification of institutional arrangements consisting of *hierarchy*, *market*, and *collective action*, which he refers to as allocation mechanisms for goods and services. Hierarchy is characterized by command and control from the top down and is a feature of governments and other large organizations. Political and sociological theory often is used to explain behavior within hierarchies. Markets are characterized by voluntary, impersonal exchanges of goods and services between buyers and sellers, such as among private agents or firms. Neoclassical economic theory is typically used to explain market behavior. A third, albeit less well understood type of arrangement is characterized by collective action or participatory decision-making based on conventions, customs, or codes of conduct. According to Ostrom, Shroeder, and Wynne (1993), individuals will organize into formal and informal organizations for collective action to create jointly used goods and services if they perceive that the resulting benefits (including benefits shared with others) exceed the costs of the resources invested. Olson (1971) and others have identified some of the determinants of success in collective action.

Relevance to the Study of Maize Seed Industries

What is the relevance of these various paradigms to the study of maize seed industries? The neoclassical model accurately attributes a utility-maximization motive to economic activity and correctly depicts the process by which supply and demand are equilibrated through negotiated exchanges taking place in a market context, making it a powerful tool for understanding any industry, including the seed industry. Its usefulness for applied analysis is limited, however, because it fails to account adequately for transactions costs. The depiction of fully informed, completely rational economic agents working within well-functioning, frictionless institutions is often misleading. The problem lies not in the assumption that decision makers act rationally, but rather in the assumptions that information flows are perfect and transactions are costless. When these latter two assumptions are violated (as they nearly always are), numerous institutional problems arise that market forces cannot in themselves supersede (Klitgaard 1991).

The institutionalist model avoids this problem by recognizing many of the institutional factors that influence behavior in the real world, but it does not fully explain where these institutions come from and how they change. This shortcoming is particularly limiting in the context of economic development, because economic development is a process by which institutions undergo change over time.

The Marxian model introduces dynamism into the analysis by allowing for the possibility of institutional change, but it asserts that change is driven by a deterministic historical dialectic that is essentially impervious to marginal collective action (according to the Marxian view, nothing short of revolution is capable of effecting fundamental change). The Marxian view thus leaves little role for discretionary incremental policy, limiting its value as a tool for applied policy analysis.

Which leaves the new institutional economics. The NIE paradigm incorporates many attractive features of the other three. It accommodates the utility-maximizing nature of most economic activity, recognizes the many institutional factors that influence real-world behavior, and endogenizes the process of institutional change by focusing on the rules and norms that determine the incentives for and constraints on the decisions of economic agents. In addition, it explicitly takes into account the important relationship between the characteristics of products and alternative forms of economic organization.

New institutional economics approaches have been used to analyze labor markets, contract markets, and insurance markets in agriculture (see Bardhan 1989; Nabli and Nugent 1989a, 1989b). They have not been used extensively to analyze seed markets, however (significant exceptions include Butler and Marion 1983; Schmid 1987; Butler and Schmid 1984). The relative lack of attention to seed markets is curious, because NIE concepts, when combined with ideas from the neoclassical and the Marxist paradigms, are well suited for analyzing seed industries. Valuable insights can be gained by evaluating alternative forms of seed industry organization in terms of their ability to economize on transformation and transactions costs. Knowledge of the relationship between product characteristics, organizations, institutions, and economic incentives can help in the formulation of hypotheses about the outcomes that are likely to ensue from alternative forms of seed industry organization.

An Integrated Conceptual Framework

Combining ideas drawn from the various paradigms allows us to develop the following integrated conceptual framework that can be useful in identifying forms of industrial organization and supporting institutional arrangements likely to bring about good performance in the maize seed industry.

Individuals maximize their utility subject to economic and noneconomic constraints. They often find it advantageous to organize into groups (i.e., to form organizations) in order to pursue common objectives. The relationships between the members of an organization, between members and nonmembers, and between different organizations are governed by formal and informal rules. These rules or behavioral regularities constitute institutions. Although institutions can be defined in different ways, according to most definitions, institutions are configurations of rules that (1) shape individual choices, (2) govern

voluntarily or coercively the relations among individuals and groups, and (3) recur in predictable ways (Nabli and Nugent 1989a).

Organizations of importance to the maize seed industry include public organizations, private organizations, and voluntary organizations, as well as others representing combinations of these "pure types." The three pure types (public, private, voluntary) provide a useful starting point for analysis by forming a triangular surface representing the universe of possible organizational types. Most of the organizations associated with maize seed industries fall somewhere between the three extremes (Figure 1).

Relationships within and between organizations are influenced by institutions. Institutions, which are shaped by historical circumstances and organizational efforts, include not only the formal rules, laws, and regulations that explicitly govern the activities of economic agents, but also the wider set of legal regulations, cultural beliefs, and ethical norms that influence all human behavior. The institutions found in any given country at any given moment are determined, among other factors, by the ability of competing interest groups to exercise political, economic, and/or social power, which they use to put in place and perpetuate institutions that serve their own interests.

Different types of organizations are better suited than others to certain forms of decision-making and tend to rely more heavily on those forms to which they are particularly well suited. Economic transactions tend to be conducted hierarchically in public organizations, through negotiation in private organizations, and collectively in voluntary organizations. The relationship between organizational type and decision-making form is not deterministic, however. For example, public plant breeding institutes typically rely on hierarchical decision-making to guide production and consumption activities, but administrators frequently take market factors into account in determining the supply of inputs and assessing the demand for outputs. Similarly, private seed companies normally rely on market transactions to coordinate production and exchange activities, but within the firm decisions are often made hierarchically. Seed cooperatives are usually organized and sustained through collective action, but they sometimes pursue profit-maximization goals normally associated with private firms.

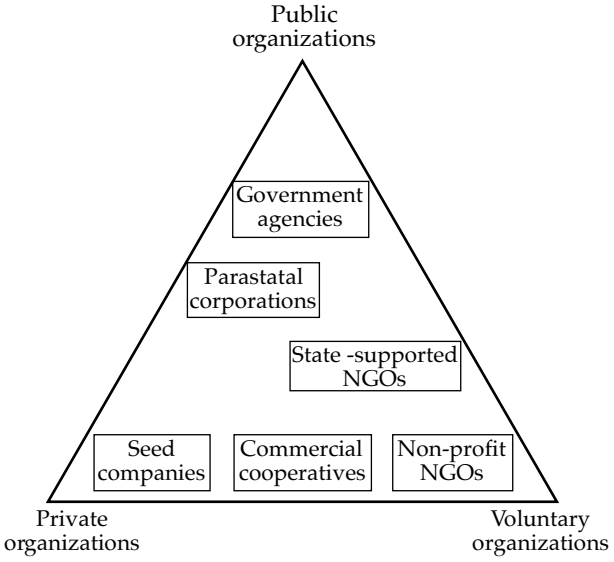

Figure 1. Universe of organizational types showing selected seed industry organizations.

While alternative organizational/institutional combinations may or may not differ in their capacity to reduce transformation and transaction costs, they certainly differ in their ability to shift around transformation and transaction costs in ways that benefit some interest groups

and hurt others. In the maize seed industry, as in any industry, the levels and distribution of benefits and costs depend on the interaction between the attributes of products, the organization used to provide those products, the institutional arrangements that shape the behavior of economic agents, market structural conditions, technology, and other factors. Since seed industry performance is measured in terms of the levels and distributions of cost and benefits, "good" performance (which is subjectively defined) depends on the ability of a particular combination of organizations and institutions to produce a desired set of outcomes. The likelihood that a desired set of outcomes will be achieved varies according to where different activities are distributed across the triangle. Whether or not a given configuration succeeds in producing a desired outcome depends not only on the attributes of the product involved, but also on the set of supporting institutions that are in place, on market structural conditions, and on technology. As these factors change, the appropriateness of the organizational type can be expected to change.

Important Attributes of Maize Seed

Before evaluating the usefulness of this integrated conceptual framework by relating it to empirical evidence on the development of selected national seed industries, it is worth considering the seed industry's principal product. As we have seen, product characteristics can be expected to influence production and consumption incentives, so it is important to examine the attributes of maize seed.

Maize seed, like all seed, is really two things in one. First, it is a *consumable input*, i.e., something that farmers can combine with other inputs (e.g., land, labor, water, fertilizer, pesticide) to produce a crop. At the same time, maize seed is also a *source of germplasm*, i.e., a store of genetically encoded information that determines how other inputs combine and become transformed into useful products. Practically speaking, these two things are difficult to separate, in the sense that a farmer who purchases a bag of seed in order to acquire the consumable input needed for planting cannot avoid purchasing the genetically encoded information that is contained in the seed.[3]

The fact that maize seed represents two fundamentally different things is significant. Although maize seed considered as a consumable input and maize seed considered as a source of germplasm have many attributes in common, they differ with respect to two attributes that turn out to be important in shaping the incentives for seed organizations to produce seed and for farmers to consume seed: *subtractability* and *excludability*.

Subtractability

Subtractability refers to the degree to which use of a good or service by one person precludes use by another person. Maize seed considered as a consumable input has high subtractability in the sense that two farmers cannot use the same bag of seed. If one farmer plants a bag of seed, that same bag of seed can no longer be planted by another farmer. But

[3] Although the genetically encoded information may be difficult for the farmer to access or copy (as in the case of hybrids), technologies now exist that allow almost any form of germplasm to be mapped at the molecular level and eventually reproduced.

maize seed considered as a source of germplasm has low subtractability. If one farmer purchases a bag of seed in order to make use of a particular OPV or hybrid, this does not prevent other farmers from using the same OPV or hybrid. Assuming the other farmers are able to purchase different bags of seed, their use of the same germplasm neither directly affects nor is directly affected by the first farmer's use.[4,5]

Excludability

Excludability refers to the ease with which the seller of a good or service can deny access to unauthorized users. Maize seed considered as a consumable input has high excludability, meaning it is cheap to exclude unauthorized users. Sellers of maize seed can deny access to unauthorized users simply by refusing to provide them with seed if the unauthorized users do not pay the asking price. But the degree of excludability is quite different for maize seed considered as a source of germplasm. In principle, the germplasm contained in maize seed should have low excludability (meaning it is expensive to exclude unauthorized users), since unauthorized users can gain access to germplasm by obtaining a few kernels of seed. In practice, however, because of differences in the way OPVs and hybrids reproduce, the degree of excludability varies. The germplasm in OPV seed has low excludability, because OPV seed is easily reproducible; if an unauthorized user manages to obtain a few seeds of an OPV, more seed can easily be produced. But the germplasm in hybrid seed has high excludability, because hybrid seed can be reproduced only by those who know the pedigree or have access to the parent lines.

Transparency

Although differing in terms of subtractability and excludability, maize seed considered as a consumable input and maize seed considered as a source of germplasm share a third attribute that affects production and consumption incentives. *Transparency* refers to the degree to which the characteristics of a product are clearly evident. Like all seed, maize seed is nontransparent in the sense that potential users cannot easily make quality determinations. It is very difficult to judge the quality of maize seed simply by looking, because seed has a number of characteristics that are difficult to recognize and measure. The nontransparency attribute pertains both to maize seed considered as a consumable input (in which case the difficulty lies in determining varietal purity, viability, health, etc.) and to maize seed considered as germplasm (in which case the difficulty lies in determining the genetic composition).

Seed Attributes and Production/Consumption Incentives

The nontransparency characteristic of maize seed (which is unchanging) and the subtractability and excludability characteristics (which differ depending on whether seed is being considered as a consumable input or as a source of germplasm) have important

[4] However, indirect effects are possible (for example, when use by other farmers of seed of a particular OPV or hybrid affects market prices).

[5] Subtractability, sometimes referred to as *nonrivalry,* can also be described in terms of the cost incurred by current users when additional users are allowed (Schmid 1987). Thus, the subtractability of seed considered as a source of germplasm is low, because as additional farmers adopt a variety or hybrid, those who are currently growing the variety or hybrid do not incur any direct cost. But subtractability of seed considered as a consumable input is high, because as additional farmers begin to plant seed from a given lot, farmers who are currently using that lot incur a direct cost in terms of decreased availability of seed.

implications for the optimal organization of national maize seed industries, because they affect the economic incentives facing seed producers and consumers.

The nontransparency of maize seed creates an information asymmetry between sellers and buyers. In most negotiated market transactions involving seed, the seller knows the quality of the seed, but the buyer does not. Thus, transactions involving maize seed always involve some degree of uncertainty for the buyer. Under these circumstances, buyers of maize seed must either invest time and effort in determining the quality of the seed (which is costly), or they must rely on some other means of reassuring themselves that the seed is likely to be of good quality. One way to do this is through regulation, as when an independent agency is empowered to enact and enforce seed quality standards. Another way that buyers reassure themselves of seed quality is to purchase seed only from companies whose seed is known to have been good in the past (brand loyalty), on the assumption that these companies will continue to produce good seed in the future.

Unlike the problems caused by lack of transparency, the problems caused by the subtractability and excludability characteristics of maize seed depend on the type of seed involved and on the use to which it is put. Considered as a consumable input, maize seed has high subtractability and high excludability. But considered as a source of germplasm, maize seed has variable subtractability and excludability characteristics. While the degree of subtractability is always low, the degree of excludability depends on whether the seed is OPV seed or hybrid seed. The low subtractability of maize seed considered as a source of germplasm, coupled with the variable excludability (low for OPVs, high for hybrids), suggest that the institutional arrangements needed for effectively developing, producing, and distributing improved maize seed will tend to differ.

The combination of high subtractability and high excludability is associated with products that are effectively handled through markets. Sellers have incentives to provide the product, buyers have incentives to pay for the product, and market failures are unlikely. Because of the high subtractability, unauthorized users have little opportunity to act as free riders; for example, as mentioned previously, a farmer cannot plant a bag of seed once it has been planted by someone else. Because of the high excludability, sellers are able to realize a return on their investment, since they can easily deny access to unauthorized users who refuse to pay the asking price. Thus, buyers have an incentive to demand seed through the market, and sellers have an incentive to supply seed through the market, and in the absence of distortions the market will clear at prices and quantities that maximize social welfare.

The combination of low subtractability and low excludability is associated with products that cannot always be handled effectively through markets. Sellers are likely to have difficulty realizing a return on their investment because they cannot easily exclude unauthorized users. Under these circumstances, private companies are likely to underinvest in OPV research, since they cannot expect to capture the full benefits through seed sales.[6] Therefore, reliance on a market solution is likely to result in production and consumption of

[6] In most developing countries, the basic research needed as a prerequisite to the development of improved maize germplasm has already been done. What is needed now is applied research to adapt existing germplasm to specific environmental conditions, as well as to develop finished commercial materials.

OPV germplasm at socially suboptimal levels. This suggests that some form of government or collective action will probably be needed to ensure that adequate OPV research takes place. Numerous options exist for ensuring investment in OPV research; one strategy is to combine public research on OPVs with public, private, and/or collective seed production, all subject to regulation and monitoring. No strategy will be perfect, however, because the combination of low subtractability and low excludability is fraught with potential institutional hazards. In addition to the problem of free-riding, there are difficulties with measuring the demand for and benefits of OPV germplasm. And whenever there is public funding of provision, opportunities arise for rent-seeking behavior, since government decisions regarding OPV research confer unearned advantages to particular individuals or groups.[7]

The combination of low subtractability and high excludability is associated with products that potentially can be handled effectively through markets. Sellers will be assured a return on their investment, however, only if the high excludability can be maintained. Traditionally, the high excludability of hybrid maize seed has been maintained through the "trade secrets" method, under which seed companies decline to release information about pedigrees and/or refuse to provide access to parent inbred lines. More recently, as advances in technology have made it easier (and cheaper) to defeat the trade secrets strategy by identifying and replicating successful commercial hybrids, seed organizations have turned with increasing frequency to the courts in an effort to maintain the high excludability of their proprietary hybrids (i.e., through intellectual property rights laws). In addition, they use advertising to convince buyers that their brand (of essentially the same product) is superior to other brands.

In summary, the attributes of maize seed greatly influence production and consumption incentives. The lack of transparency restricts the ability of potential buyers to make quality determinations, which exposes them to the risk of unexpected losses and decreases their willingness to buy. The subtractability and excludability characteristics affect the ability of seed organizations to realize benefits through sales, which depending on the circumstances either increases or decreases their willingness to sell.[8] Incentives to supply seed are generally very low for varietal crops, especially self-pollinating varietal crops such as wheat and rice, because farmers generally do not purchase commercial seed of these crops on a regular basis. If they cannot obtain seed from a relative or neighbor, they may initially purchase seed of a new variety, but after the first cropping season it is usually economical to plant recycled seed saved from their own harvest.[9] But economic incentives to supply seed are usually much greater for hybrid crops, because farmers tend to purchase commercial seed of these crops quite frequently.

---

[7] Rent-seeking behavior is particularly likely to arise when private companies are allowed to appropriate and make exclusive use of the benefits of public research.

[8] Subtractibility by itself does not affect the ability of a seed organization to recover its production costs, but the degree of subtractibility does determine whether or not the amount supplied is socially optimal. If the marginal cost incurred by a seed organization in providing a particular OPV or hybrid to additional buyers is zero, then the socially optimal amount will be produced only when the marginal value of the last unit consumed is zero also. Normally seed organizations will choose to maximize their profits by supplying less than the socially optimal quantity.

[9] A number of European countries have recently introduced measures designed to overcome this problem by requiring farmers to pay an annual licensing fee for the use of farmer-produced varietal seed.

The variability in economic incentives to supply different types of seed is reflected in varying levels of participation of the private sector in different segments of the market for commercial seed. Private seed companies tend to be very active in producing and selling seed of hybrid crops, but they are usually far less active when it comes to varietal crops.

Explaining the Evolutionary Process

How do maize seed industries grow and evolve? From a policy perspective, an important question is whether changes in the optimal form of industrial organization occur in some sort of deterministic manner, since this would imply that efficient seed industries would tend to develop along a predictable path. Here the empirical record may provide some guidance. Recent case studies focusing on the emergence of national maize seed industries in Africa, Asia, and Latin America suggest that seed industry development often follows the same general path (see Aquino 1998; Garcia 1998; Morris 1998b; Pal, Singh, and Morris 1998; Pray 1988; Pray, Rozelle, and Jikun 1998; Rusike 1998; Rusike and Smale 1998). The findings of these case studies lend support to life-cycle theories of industrial development advanced by a number of seed industry analysts.

Stylized Stages of Seed Industry Development

Four stages of growth are commonly described, although in reality these "stages" represent arbitrarily selected points along a growth continuum (Douglas 1980; Desai 1985; Pray and Ramaswami 1991; Rusike 1994; Dowswell, Paliwal, and Cantrell 1996). The four stages of growth are summarized in Table 1.

Pre-Industrial (Stage 1). During the Pre-Industrial Stage, none of the organizations and institutions associated with a formal seed industry are evident. Germplasm improvement occurs at the farm level as farmers carefully select superior ears from their own production to use as seed in the following season. Most farmers use seed saved from their own harvest, although some may also exchange small quantities of seed with relatives or neighbors. The main seed type is OPVs. Farmers are the dominant actors because seed production technology is readily accessible to them and because few incentives exist for commercial seed production. The absence of formal organizations does not mean, however, that pre-industrial seed systems are static or inefficient; a growing body of empirical evidence suggests that informal seed systems are often dynamic, flexible, and relatively efficient at performing the essential activities of germplasm maintenance/improvement, seed production, and seed distribution (Almekinders, Louwaars, and de Bruijn 1994). The particular virtues of many pre-industrial seed systems include their ability to provide small-scale producers with affordable seed of familiar, locally adapted materials in a timely and cost-effective manner (Cromwell 1990).

Emergence (Stage 2). During the Emergence Stage, the realization that specialized knowledge and skills are needed to carry out germplasm improvement work leads to the formation of specialized research organizations. Since the predominant seed type is still OPVs, few incentives exist for plant breeding research and/or commercial production and distribution of seed, so government agencies are needed to conduct research, multiply breeders' seed released by the research organizations, and distribute commercial seed to

farmers. Until farmers learn to appreciate the benefits of high quality seed, they are unwilling to pay higher prices, and often it must be distributed at subsidized prices. Once a significant number of farmers appreciate the value of using quality seed, a few specialized seed production firms begin to multiply and distribute seed released by the government research stations. When present, seed certification and testing functions are performed by the government.

During the Emergence Stage, the state tends to be the dominant actor, because a centralized government organization can most efficiently undertake plant breeding activity; conduct varietal evaluation trials; produce foundation seed; multiply, condition, certify, and test commercial seed; and distribute it to farmers. Since the demand for seed is still highly uncertain, private firms have little incentive to invest in specialized research facilities and seed multiplication sites, especially when there are few institutional safeguards in place to ensure that the returns to these investments can be appropriated. Market expansion must occur in order to create incentives for private firms to be formed, yet market expansion is unlikely unless farmers are able to obtain reliable information about seed quality (Klitgaard

Table 1. Characteristics associated with the stages of maize seed industry development

Characteristic	Stage 1: Pre-industrial	Stage 2: Emergence	Stage 3: Expansion	Stage 4: Maturity
Orientation of agriculture	Subsistence	Semisubsistence	Mostly commercial	Completely commercial
Predominant seed technology	OPVs	OPVs, some hybrids	Some OPVs, hybrids	Hybrids
Seed procurement practices	On-farm production, farmer-to-farmer exchange	On-farm production, farmer-to-farmer exchange, some purchasing	Frequent purchasing	Annual purchasing
Seed production	On-farm	On-farm, public organizations	On farm, public organizations, private companies (national)	Private companies (global)
Seed market coverage	Local	Local, regional	Local, regional, national	Local, regional, national, global
Sources of seed information	Direct experience, other farmers	Public agencies	Private seed companies	Private seed companies
Locus of seed research and development	On farm	Public organizations	Public and private organizations	Public and private organizations (specialized)
Supporting legal systems	Customary law	Civil	Commercial (domestic)	Commercial (global)
Intellectual property rights	None	None	Trade secrets	Plant varietal protection, patents

Source: Compiled by the authors.

1991). As farmers increase adoption of high quality seed of improved OPVs and hybrids, agricultural productivity rises; resources become available for buying seed, fertilizer, and other scientific inputs; farmers increase their demand for proprietary hybrids; and the industry is driven into a phase of rapid expansion.

Expansion (Stage 3). During the Expansion Stage, markets become increasingly commercialized, and the dominant seed type changes to hybrids. Private firms assume an increasingly important role in carrying out plant breeding work; conducting varietal evaluation trials; producing foundation seed; multiplying, conditioning, and testing commercial seed; and distributing it to farmers. Legal codes of conduct are enacted to guide public-sector plant breeding, enforce seed certification procedures, and regulate the seed trade. Trade secrets laws evolve to provide protection for private sector investment in the seed industry. As private seed companies increase their level of investment, they voluntarily ensure that seed quality standards are maintained and use a combination of government certification and brand names to develop a reputation for product quality. As farmers move up the quality ladder, they adopt improved management practices. Market competition helps assure seed quality, because farmers do not make repeated purchases from companies that market inferior products. Although government seed services continue to enforce seed quality control and phytosanitary standards for international trade in seed, responsibility for seed certification and laboratory testing is transferred to the private sector, with the role of government reduced to that of monitoring private sector activity.

Maturity (Stage 4). During the Maturity Stage, private firms dominate varietal development; foundation seed production; multiplication, conditioning, and testing of commercial seed; and marketing and distribution activities. As competition for market share intensifies, the private seed industry consolidates through mergers, acquisitions, and strategic alliances among seed companies and agrochemical firms. Ever greater investment in research coincides with the enactment of intellectual property rights laws such as plant breeders' rights and plant patents, stimulating additional investment in seed enhancement processes, biotechnology, and information technology. Private firms use a mix of brand names, logos, trademarks, advertising, field demonstration, personal selling, and agronomic advice signals to inform farmers about the characteristics of their products. Seed companies develop global research, seed multiplication, and distribution networks coordinated from headquarters located in industrialized countries. Meanwhile, unremunerative activities are left to the state, such as the collection, evaluation, and conservation of genetic resources, as well as the management of varietal evaluation trials. Government programs emphasize crops and regions that fail to attract the attention of private firms, which results in a division of labor between public and private organizations and specialization designed to reduce duplication of efforts. In addition, the state plays an important role in setting and enforcing rules governing the industry.

Evolutionary Forces in Seed Industry Development

What are the forces driving the seed industry to develop along this stylized path? A number of theories have been proposed by economists to explain the process of technical and institutional change. Notable among these have been the various models of induced innovation, which come in "demand push" versions emphasizing the importance of changes in market demand on the supply of knowledge and technology (Griliches 1957), as

well as "supply pull" versions emphasizing the importance of factor prices (Hayami and Ruttan 1970, Binswanger 1974).

The induced innovation models are useful in that they focus attention on the processes through which exogenous changes in the economic environment influence technological development and industrial transformation, but they shed little light on the underlying learning, search, and formal research and development processes. This shortcoming has fueled a revival of interest in evolutionary theories of technical and institutional change. As propounded in the influential writings of Richard Nelson and Sidney Winter (Nelson and Winter 1973, 1974, 1982), the evolutionary models build on the behavioral theory of the firm in an effort to explain the internal workings of the black box, an area all but ignored by the neoclassical induced innovation models. Instead of describing behavior in simple utility-maximizing terms, the evolutionary models describe decision-making as being dominated by fixed behavioral patterns or routines – for production activities, personnel actions, choice of product mix, research, and development. Some versions also accommodate a search and selection process that incorporates elements of rational choice (Ruttan 1996).

Although evolutionary models have provided important new insights into processes of technical and institutional change, the precise nature of these processes continues to defy easy description. In a recent review of the literature, Nelson (1995) writes, "In many cases the evolutionary processes at work seem to involve a blend of market, professional, and political processes, and it is likely an enormous task to sort these out and get an accurate assessment of operative 'fitness' criteria and selection mechanisms."

But just because the selection processes are difficult to describe does not mean that they are entirely random. As North and others have pointed out, if organizational structures and institutional arrangements succeed in increasing profits and/or productivity, aggregate welfare is enhanced (i.e., profits are increased), and the adaptations are likely to endure. On the other hand, if organizational structures and institutional arrangements do not succeed in increasing profits and/or productivity, aggregate welfare is not enhanced, and the adaptations are unlikely to endure indefinitely. But neither outcome is inevitable, as what actually happens may be influenced by many factors, including the distribution of political and economic power.

Nelson (1995:83) suggests that in the now industrialized nations, mechanisms must have existed that somehow made the co-evolution of organizations, institutions, and technology move in directions that have led to sustained economic progress, but he argues that it would be incorrect to view this as an optimization process, since the range of possible outcomes is not well defined, and because the interests of different participants often conflict. Curiously, even though optimization is not taking place, there appear to be forces that stop or reverse processes of organizational and institutional evolution which, if pursued, would lead to disastrous consequences.

So what motivates the recurring pattern of organizational and institutional transformation that gives rise to the seed industry life-cycle? Although the still primitive state of our ability to work with evolutionary theories of industrial growth for the time being prevents us from coming up with a definitive answer to this question, knowledge of technology, economics,

organization theory, and the behavioral sciences points toward the direction from which answers surely must come. National maize seed industries evolve as the organizations engaged in research, seed production, and seed distribution respond to changing external circumstances in ways that help them to realize their own particular objectives. Efficiency considerations are important in this process, because regardless of their objectives, organizations that operate efficiently are more likely to survive. In their drive to achieve increased efficiency, seed organizations assume forms and adopt operating practices that allow transformation and transactions costs to be minimized; organizations that fail to achieve efficiencies have difficulty surviving.

The process is not completely deterministic, however, because it does not always unfold in exactly the same way in every country. It is in fact path dependent in the sense that the particular organizational structures and institutional arrangements that survive in the long run are influenced to a greater or lesser extent by events, to a considerable extent random, that happened earlier. Thus, in countries where historical forces have fostered the emergence of a thriving merchant class, privatization of the seed industry is likely to be spearheaded by large numbers of small-scale local firms. In contrast, in countries where an established merchant class is lacking (perhaps because the emergence of such a class was discouraged by colonial rulers), privatization of the seed industry is likely to feature an invasion by large transnational corporations.

Outcomes of the Industrial Growth Process

From a policy perspective, it is important to note that the drive to achieve increased efficiency not only motivates the behavior of individual organizations, but it also affects the structure of the industry. As the theory predicts (and as the empirical record confirms), efforts on the part of individual maize seed organizations to achieve increased efficiency drive the maize seed industry as a whole toward *concentration* and *vertical integration*. These two trends are worth discussing briefly, because they have implications for the long-run performance of all national maize seed industries.

Concentration. As a national seed industry becomes more concentrated, the individual organizations that make up the industry grow in size. By growing in size, the organizations are able to exploit potential economies of scale. But exactly where can economies of scale potentially be achieved? Are they equally important in research, seed production and conditioning, and seed distribution?

Research. Maize research requires three basic ingredients: properly equipped and appropriately situated facilities, skilled and experienced staff, and a plentiful supply of breeding materials. Until recently, none of these three key ingredients has been particularly difficult to come by, which is why commercial breeding programs have been able to operate successfully on a small scale. The economics of maize research are changing rapidly, however, and increasingly there are advantages to being big. In conventional breeding programs, economies of scale relate not so much to the physical process of screening germplasm, making selections, combining materials, and evaluating progeny, since these are labor-intensive activities that are best carried out on a fairly small scale. As competition in the industry intensifies, however, success in conventional plant breeding depends increasingly on having access to a wide range of superior germplasm and in being able to

test experimental materials in many different locations. These are things that small organizations generally have difficulty managing for themselves. In contrast, the large transnational seed companies all have established international networks of research stations and testing facilities that allow experimental materials to be moved around the world and evaluated in many different locations. The transnationals have thus bypassed the public-sector international testing network upon which global maize breeding efforts traditionally have depended. Companies that are able to build and operate these global networks enjoy a distinct advantage over national programs and local seed companies, whose spheres of operation are limited. This explains why the number of organizations engaged in maize breeding research is declining and why the size of surviving breeding programs is increasing.

The trend toward concentration in maize research has accelerated with the rise of biotechnology, which has greatly increased costs. Although the three key ingredients of research have not changed, the cost of equipping facilities and training scientists needed to carry out biotechnology research has increased exponentially. This has put many cutting-edge technologies out of reach of all but the biggest organizations (which are able to mobilize large amounts of investment capital). The prospect of reaping enormous profits from sales of genetically engineered hybrid maize seed, as well as from the complementary chemical inputs that the new hybrids will require, has fueled a frenzy of mergers, acquisitions, and joint licensing agreements throughout the global biotechnology industry as the leading players seek access to key technologies.

Seed production and conditioning. Unlike research, seed production is an activity best carried out on a relatively small scale. The main reason for this is that the biological process of reproduction in maize is very sensitive to environmental influences and can be controlled effectively only through intensive, hands-on management. Large-scale production of genetically uniform, high quality hybrid maize seed may become a reality some day, but for the time being the process requires constant vigilance. This is why most commercial seed companies continue to work with contract growers; only contract growers can be counted on to provide the attention needed to produce a successful seed crop.

Seed conditioning also is an activity most effectively performed on a relatively small scale. Although the technical and economic efficiency of seed conditioning operations can be improved through the use of industrial machinery, as the scale of conditioning operations increases, these gains are soon offset by the increased cost of transporting unprocessed seed to the plant, as well as by the increased difficulty of coordinating greater quantities of product.

Seed distribution. At first glance, it is not clear why seed distribution activities should be characterized by economies of scale. The technology involved in distributing seed is after all simple, and investment requirements are modest. As many small companies have demonstrated, all that is really needed to distribute seed is a storage facility, reliable transport, and a network of marketing agents willing to handle the product. But physically delivering seed to the farmer is only part of the distribution process. The other part is getting the farmer to buy. For this to happen, the farmer must understand the benefits of improved seed and trust in the quality of the particular lot being offered. And this is where

economies of scale come in. Large organizations, particularly diversified corporations that derive income from a range of products and services, are in a much stronger position than small organizations to undertake advertising and promotional activities. Their large size increases the expected revenues from seed sales and permits a larger absolute investment in advertising; this is important, because once brand name recognition is established, attracting and retaining customers becomes easier. Their diversified nature allows them to draw on alternative sources of revenue, enabling them to cross-subsidize seed market development activities during an initial start-up phase and/or to continue operating during occasional years of poor performance. Finally, large companies generally have an easier time raising capital than do small companies. Since access to low-priced capital reduces inventory costs and increases a company's ability to survive occasional lean years, access to low-priced capital is an important consideration in the seed distribution business.

Vertical integration. Concentration in the maize seed industry is advantageous when it allows organizations to capture economies of scale in production. But concentration can be a mixed blessing, because it involves an increase in the average size of seed organizations, and increased size generally means increased risks. If a small seed organization goes under, the losses will be considerably smaller than the losses suffered if a large organization goes under.

Maize seed organizations, like other organizations, respond to increased risk by seeking out mechanisms designed to improve coordination between successive stages of economic activity. One such mechanism is vertical integration, which occurs when successive stages of economic activity carried out by separate firms are combined within the same firm. Vertical integration allows seed organizations to reduce transactions costs by eliminating the uncertainty that arises when research, seed production, and seed distribution activities must be coordinated through market exchange mechanisms.

Opportunities to reduce transactions costs through vertical integration can be found throughout the continuum from research to seed production to seed distribution. As the cost of research rises, research organizations face increasing losses if they are unable to recoup their research investment through sales of germplasm products; this creates strong incentives for them to integrate downward into seed production and distribution. Similarly, as establishing a market presence and developing brand name recognition becomes increasingly costly, distributors face increasing losses if they are unable to maintain access to a continuing stream of high-quality products; this creates strong incentives for them to integrate upward into seed production and research.

In the private sector, vertical integration is by now a fact of life. In today's competitive market, most private seed companies carry out research, produce seed, and distribute seed. The fact that all three activities are carried out by each company has a number of advantages. First and most important, vertical integration allows the risks associated with individual activities to be greatly reduced. Thus, the research division is ensured an outlet for its products; the seed production division is ensured a steady supply of high-quality hybrids, as well as a reliable outlet for the commercial seed it produces; and the marketing and sales division is ensured an adequate supply of quality product. Second, because research, seed production, and seed distribution activities are carried out within the same

corporate entity, profits and losses can be distributed in a way that maximizes the objectives of the firm, even if this means cross-subsidizing certain inherently unprofitable activities. Third, vertical integration makes it easier to protect valuable products, processes, and information by keeping them within the company.

The advantages of vertical integration become especially clear when the performance of transnational seed companies is compared to that of public seed organizations. By and large, vertical integration is still relatively uncommon in the public sector. Most national maize programs continue to maintain separate organizations for research, seed production, and seed distribution. Because these organizations are usually managed by different ministries, they frequently are plagued by coordination problems. For example, researchers in public breeding programs frequently target environments other than those in which new varieties are most urgently needed, and public seed agencies often over- or underestimate the effective demand for seed.

Summary. Concentration and vertical integration in the maize seed industry are desirable in that they create opportunities for increasing efficiency. At the same time, concentration and vertical integration are undesirable in that they create opportunities for the potential exercise of monopoly power. Economic theory suggests that large firms in concentrated markets will be able to increase profits by forming cartels and colluding to set prices. Why this has not happened — not even in the extremely concentrated and vertically integrated North American and European maize seed industries — remains something of a mystery. Recent studies of pricing behavior in these industries have failed to turn up evidence that seed companies have parlayed their market power into higher prices. Maize seed prices have indeed risen in United States and in Europe, but the rises are generally consistent with increases in actual research, production, and distribution costs. Several hypotheses have been advanced to explain the continuing competitiveness of the North American and European maize seed prices. Some analysts think that strategic considerations discourage seed companies from exercising their power to influence maize seed prices. Diversified companies that sell maize seed along with other inputs may prefer to use seed as a "loss leader" in order to secure sales of more profitable chemical products (e.g., fertilizers, herbicides, pesticides). Other analysts point out that seed companies that have links to the food and/or feed industries may use low-priced seed to ensure production of steady supplies of maize grain.

Policy Implications

Maize seed industries pass through a life-cycle characterized by predictable stages of growth. The seed industry life-cycle is not completely deterministic, because historical circumstances can lead to temporary deviations from the path and/or can cause certain stages to be compressed or even skipped entirely. The industry life-cycle is predictable, however, in the sense that the emergence, growth, and maturation of the seed industry are driven by processes that are very difficult to reverse (e.g., technical change, market intensification, the accumulation of farmer knowledge).

At different stages in the seed industry life-cycle, different combinations of organizations (and different sets of supporting institutions) will be most efficient at producing needed products and services. Organizational and institutional change is thus a normal and indeed necessary feature of seed industry development.

Within a given country, at the same point in time different segments of the seed market will usually be at different stages of development. This suggests the need for heterogeneous maize seed industries in which different organizations and institutions serve different groups of growers.

National Public Organizations

Public organizations are well suited to perform many activities that are vitally important for the maize seed industry. During early stages of the industry life-cycle (emergence and growth stages), public organizations normally will assume a leading role in research, seed production, and seed distribution activities. During early stages of the industry life-cycle, these activities provide few opportunities for cost recovery, so subsidization is necessary. Public organizations are well suited for carrying out inherently unprofitable activities because they are free to pursue noneconomic objectives and because they operate using internally administered decision-making processes that do not have to respond to market-transmitted price signals.

During later stages of the seed industry life-cycle (growth and maturity phase), economic incentives emerge to attract the participation of private organizations. When this happens, the very characteristics that once proved advantageous for public organizations will become a liability, and they will find themselves displaced from certain activities that profit-seeking private seed companies are able to perform more efficiently (e.g., applied research, seed production, seed distribution). As the maize sector becomes more and more commercialized, public organizations gradually assume new roles involving the production of goods and services that do not provide attractive profit opportunities (e.g., basic research, research targeted at marginal environments, production of seed for subsistence farmers), and coordination of economic activities carried out in the private sector (e.g., varietal testing and release, seed quality control, regulation of seed prices, implementation and enforcement of intellectual property rights).

International Public Organizations

International public organizations have little direct involvement in maize seed production and distribution; only in research do international public organizations play a prominent role. The International Maize and Wheat Improvement Center (CIMMYT) holds the global mandate for maize research, which it pursues through a diversified portfolio of research, training, and institution-building activities. In accordance with its global mandate, CIMMYT focuses on activities that national public organizations are unable or unwilling to perform. These include providing a secure repository for an extensive collection of maize genetic resources; serving as the hub of a global germplasm improvement, testing, and exchange system designed to facilitate worldwide flows of germplasm and information; conducting strategic plant breeding and crop and resource management research; facilitating the transfer of research methods and products from industrialized to developing countries; and providing training for maize researchers.

Since CIMMYT was founded in 1966, the Center's role has evolved in response to changes in the physical and political environment in which it operates. As national maize research programs have grown stronger, CIMMYT has shifted its efforts away from the development of finished varieties suitable for direct release to farmers toward the development of intermediate germplasm products designed to serve as inputs into local breeding programs. As adoption of hybrids has increased in many developing countries, CIMMYT's work on OPVs has been scaled back in favor of increased emphasis on hybrid development activities. And as private companies have become more visible in global germplasm improvement efforts, CIMMYT has forged new links to the private sector.

The role of CIMMYT will change further as the global seed industry continues to evolve. As a public organization, CIMMYT will be most effective concentrating on the production of goods and services that do not provide clear profit opportunities and therefore are unlikely to attract the attention of private companies. One activity that seems very likely to increase in importance is the development and distribution of broadly adapted inbred lines with high combining ability for use by small- and medium-scale private national seed companies. Because they operate in limited markets, private national seed companies will often be unable to mount breeding programs of sufficient size to compete effectively with large transnational companies having access to global networks of research and testing facilities. Private national seed companies therefore are likely to look to CIMMYT as a source of materials and technologies needed to compete effectively with the transnationals. The survival of private national seed companies is important, because such companies often wield influence far beyond their size; by providing farmers with an alternative source of seed, they introduce a measure of competition into the market and in so doing exert downward pressure on prices.

Another activity likely to increase in importance for CIMMYT involves the development of improved germplasm adapted to specialized production environments, particularly stressed environments subject to extreme temperatures (heat or cold) and/or moisture levels (drought or waterlogging). Maize growers located in these environments generally do not represent an attractive market for commercial seed, so their needs are unlikely to attract the attention of private firms. Public organizations such as CIMMYT can play an important role in providing genetic resources for these stressed environments.

A third area in which CIMMYT is likely to play an increasingly important role is in facilitating technology flows. Because CIMMYT is widely perceived as a neutral player in the global seed industry, it is ideally suited to serve as a conduit for channeling intellectual property from private firms in the industrialized world to public organizations and private firms in the developing world. CIMMYT could accomplish this either by providing credible assurances about how technologies would be used or by itself seeking so-called "protective" patenting of its own technologies in order to ensure free access to a wide range of users.

Private Seed Companies

Because they take their cues from market-transmitted price signals, private seed companies are able to coordinate certain types of economic activity much more rapidly and effectively than public organizations operating via centrally administered decision-making processes.

Private companies thus are particularly well suited to carrying out activities that require flexibility and rapid response time.

During the early stages of the seed industry life-cycle, when farmers are still learning about the advantages of improved germplasm and when effective demand for commercial seed is still weak, private companies will have little incentive to participate in the seed industry. But as soon as there is effective demand for improved seed, private companies will see that it is potentially profitable to enter into the seed business. Initially, the returns from the production and distribution of seed are unlikely to allow full recovery of research costs, so private companies will choose to produce and sell seed of public OPVs and hybrids. Experience from around the world suggests that private companies are usually far more successful than public seed organizations at seed production and distribution. With few exceptions, private companies have nearly always been able to outperform government seed organizations by offering better products and better customer service at equal or lower prices. The success of private companies is attributable to their ability to assimilate information about market conditions and respond to changing price signals rapidly and efficiently, as well as their constant drive to maximize profits by reducing transformation and transactions costs.

But the very characteristics that allow private companies to displace public seed organizations eventually contribute to their own undoing. As competition in the seed industry intensifies, profit margins earned by private companies decline. Eventually a point is reached where the companies can remain in business only by offering proprietary products, and they will be compelled to launch their own research programs. Many of the private companies that are able to integrate vertically into research will be able to compete successfully with public research organizations by bringing to bear the same organizational characteristics that allowed them to be so successful in seed production and distribution, i.e., their ability to assimilate information about market conditions and respond to changing price signals rapidly and efficiently.

Private maize seed companies have demonstrated that they are extremely well suited for carrying out research, seed production, and seed distribution activities. Although examples can be cited of instances in which private companies have performed poorly, on balance the record is extremely positive.

But despite their many attractive features, it is important to recognize that private seed companies are unlikely to provide all things for all people. Three instances can be cited in which exclusive reliance on private seed companies is likely to be undesirable.

First, since private companies respond to market-transmitted price signals, in order for them to operate efficiently the prevailing structure of economic incentives must be such that "good" performance is rewarded and "bad" performance is punished. When markets are not capable of transmitting the appropriate price signals (as often happens during the early stages of the seed industry life-cycle), it will not make sense to entrust seed industry activities to private companies.

Second, since the principal objective of private companies is to generate returns on shareholders' equity, private companies necessarily concentrate on activities and target markets that offer the best prospects for earning profits. But they will have little interest in serving the needs of farmers who do not represent profitable commercial markets, such as subsistence farmers located in marginal production environments.

Third, the drive for increased efficiency leads to increasing concentration and vertical integration in the private seed industry. These trends may prove undesirable in the long run if they lead to such a concentration of market power that a small number of very big companies are able to dominate the global seed industry.

Voluntary Seed Organizations

Because they elicit activity on the part of individuals who are motivated by reasons other than coercion or immediate financial gain, voluntary organizations are well suited for carrying out certain types of activities that are unlikely to be carried out by public organizations or private companies. Voluntary organizations are particularly effective for carrying out small-scale seed production activities that are too small to attract the interest of private seed companies and too limited in scope to justify the investment of scarce public-sector resources.

Voluntary organizations can be particularly effective for delivering improved seed to small groups of farmers with specialized germplasm needs, as evidenced by the success of numerous community-level seed production schemes. One recurring feature of these schemes is the relative simplicity of the technology, which must be accessible to all members of the organization in order for the organization to survive. This requirement limits the suitability of voluntary organizations for conducting research.

Final Thoughts: Catalyzing the Maize Revolution

We began this paper by pointing out that the history of varietal change in maize has differed from that of other major cereals, most notably rice and wheat. The conceptual framework outlined in the preceding pages provides insights that help to explain the puzzling lack of a green revolution in maize. In the case of self-pollinating crops, including rice and wheat, once crop improvement research has been provided by public research institutes, responsibility for seed production and distribution can be assumed by farmers themselves. Assuming economic incentives are in place to make MV adoption profitable, improved germplasm will spread largely through farmer-to-farmer seed exchanges.

As our conceptual framework predicts, however, and as the empirical record seems to confirm, a similar division of responsibilities is often unworkable in the case of maize. In many countries, germplasm improvement research for maize has been provided by public organizations, just as it was for rice and wheat. But there the similarity ends. The distinctive biological properties of maize, a cross-pollinating crop, effectively prevent most farmers from producing genetically true seed; at the same time, the unusual subtractability and excludability attributes of varietal seed greatly undermine the economic incentives needed to encourage profit-oriented firms to invest in maize research and seed multiplication activities. Development and distribution of improved maize germplasm thus requires a different

combination of organizations and institutions than those which fostered the well-known green revolutions in rice and wheat.

Identifying effective combinations of organizations and institutions capable of delivering improved maize germplasm to resource-poor farmers is not easy. The search for innovative solutions to the problem has frequently been constrained by a lack of imaginative thinking; as we have tried to show, the common practice of conceptualizing policy options in terms of simplistic "public vs. private" choices fails to consider the full range of available organizational and institutional alternatives. Complicating the challenge facing policy makers is the fact that maize seed industries pass through evolutionary stages of growth characterized by ever more sophisticated seed-based technologies, an increasing ability on the part of farmers to manage these technologies, and changing incentives to produce and consume different types of improved seed. As national maize seed industries grow and develop, the optimal combination of organizations and institutions needed to carry out research, seed production, and seed distribution activities changes. Only by recognizing the evolutionary nature of seed industry growth and by acknowledging the dynamic relationships between industrial organization and economic performance will policy makers be able to facilitate the emergence of efficient combinations of organizations and institutions needed to catalyze a green revolution in maize.

References

Almekinders, C.J.M., N.P. Louwaars, and G.H. de Bruijn. 1994. Local seed systems and their importance for an improved seed supply in developing countries. *Euphytica* 78: 207-216.

Aquino, P. 1998. Mexico. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner and CIMMYT.

Bardhan, P.T. 1989. *The Economic Theory of Agrarian Institutions*. Oxford: Clarendon Press.

Binswanger, H. 1974. A microeconomic approach to induced innovation. *Economic Journal* (Dec.).

Butler, L.J., and B.W. Marion. 1983. *The Impacts of Patent Protection on the U.S. Seed Industry and Public Plant Breeding.* Monograph 16. Madison, Wisconsin: North Central Project 117.

Butler, L.J., and A.A. Schmid. 1984. *Genetic Engineering and the Future of the Farm and Food System in the U.S.* The Farm and Food System in Transition Series No. 15. East Lansing, Mihcigan: Michigan State University Cooperative Extension Service.

Coase, R., 1960. The problem of social cost. *Journal of Law and Economics* 3(1): 1-44.

Cromwell, E.A. (ed.). 1990. *Seed Diffusion Mechanisms in Small Farmer Communities: Lessons from Asia, Africa, and Latin America.* Network Paper No. 21, Agricultural Administration (Research and Extension) Network. London, U.K.: Overseas Development Institute (ODI).

Desai, G. 1985. Understanding marketing environment for seed industry. Teaching note. Ahmedabad, India: Centre for Management in Agriculture, Indian Institute of Management.

Douglas, J.E. (ed.). 1980. *Successful Seed Programs: A Planning and Management Guide*. Boulder, Colorado: Westview Press.

Dowswell, C.R., R.L. Paliwal, and R.P. Cantrell. 1996. *Maize in the Third World*. Boulder, Colorado: Westview Press.

Garcia, J.C. 1998. Brazil. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner and CIMMYT.

Gerrard, C.D. 1995. Introduction to public sector and institutional economics. Economic Development Institute/ISSER Seminar, 18-29 September, 1995, Washington, DC, World Bank.

Griliches, Z. 1957. Hybrid corn: An exploration in the economics of technological change. *Econometrica* 25: 501-522.

Hayami, Y., and V. Ruttan. 1970. Factor prices and technical change in agricultural development: The United States and Japan, 1880-1960. *Journal of Political Economy* 78:1115-1141.
Jaffee, S., and J. Srivastava. 1992. *Seed System Development: The Appropriate Roles of the Public and Private Sectors.* World Bank Discussion Paper No. 167. Washington, DC: World Bank.
Klitgaard, R. 1995. *Institutional Adjustment and Adjusting to Institutions.* World Bank Discussion Paper No. 303. Washington, DC: World Bank.
Kloppenburg, J.R. 1988. *First the Seed: The Political Economy of Plant Biotechnology, 1492-2000*. Cambridge, U.K.: Cambridge University Press.
Morris, M.L. (ed.) 1998a. *Maize Seed Industries in Developing Countries*. Boulder, Colorado: Lynne Rienner and CIMMYT.
Morris, M.L. 1998b. Thailand. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner and CIMMYT.
Nabli, M.K., and J.B. Nugent. 1989a. The new institutional economics and its applicability to development. *World Development* 17(9): 1333-1347.
Nabli, M.K., and J.B. Nugent. 1989b. The new institutional economics and economic development: An introduction. In *The New Institutional Economics and Development: Theory and Applications to Tunisia.* Amsterdam, Netherlands: North-Holland.
Nelson, R. 1995. Recent evolutionary theorizing about economic change. *Journal of Economic Literature* 33: 48-90.
Nelson, R., and S. Winter. 1973. Toward an evolutionary theory of economic capabilities. *American Economic Review* 63: 440-449.
Nelson, R., and S. Winter. 1974. Neoclassical vs. evolutionary theories of economic growth: Critique and prospects. *Economic Journal* 84: 886-905.
Nelson, R., and S. Winter. 1982. *An evolutionary theory of economic change.* Cambridge, Massachusetts: Harvard University Press.
North, D. 1990. *Institutions, institutional change, and economic performance*. Cambridge, U.K.: Cambridge University Press.
Olson, M. 1971. *The Logic of Collective Action*. Cambridge, Massachusetts: Harvard University.
Ostrom, E., R. Gardner, and J. Walker. 1994. *Rules, Games, and Common Pool Resources*. Ann Arbor, Michigan: University of Michigan.
Ostrom, E., L. Schroeder, and S. Wynne. 1993. *Institutional Incentives and Sustainable Development: Infrastructure Policies in Perspective.* Boulder, Colorado: Westview Press.
Pal, S., R.P. Singh, and M.L. Morris. 1998. India. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner and CIMMYT.
Pray, C.E., and B. Ramaswami. 1991. *A Framework for Seed Policy Analysis in Developing Countries*. Washington, DC: International Food Policy Research Institute (IFPRI).
Pray, C.E. 1998. Turkey. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner and CIMMYT.
Pray, C.E., S. Rozelle, and H. Jikun. 1998. China. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner and CIMMYT.
Rusike, J. 1994. An Institutional Analysis of the Maize Seed Industry in Southern Africa. PhD thesis. Michigan State University, Department of Agricultural Economics, East Lansing, Michigan.
Rusike, J. 1998. Zimbabwe. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner and CIMMYT.
Rusike, J., and M. Smale. 1998. Malawi. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner and CIMMYT.
Ruttan, V. 1996. Induced innovation, evolutionary theory, and path dependence: Sources of technical change. Mimeo.
Schmid, A.A. 1987. *Property, Power, and Public Choice.* 2nd edition. New York, New York: Praeger.
Williamson, O.E. 1975. *Markets and Hierarchies: Analysis and Antitrust Implications*. New York, New York: Free Press.
Williamson, O.E. 1985. *The Economic Institutions of Capitalism*. New York, New York: Free Press.

Recent Economics Working Papers

95-01 Emerging Roles of the Public and Private Sectors of Maize Seed Industries of the Developing World
M.A. López-Pereira and M.P. Filippello

95-02 Maize Production Practices in Paraguay: Survey Findings and Implications for Research
M.L. Morris and M. Alvarez

95-03 Maize Research, Development, and Seed Production in India: Contributions of the Public and Private Sectors
R.P. Singh, S. Pal, and M. Morris

95-04 Triticale Production and Utilization in Tunisia: Constraints and Prospects
M.E. Saade

96-01 Fertilizer Use and Maize Production in Sub-Saharan Africa
P. Heisey and W. Mwangi

96-02 Understanding Global Trends in the Use of Wheat Diversity and International Flows of Wheat Genetic Resources
M. Smale and contributors

96-03 Adoption and Impact of High Yielding Wheat Varieties in Northern Tunisia
M.E. Saade

97-01 The Contribution of Genetic Resources and Diversity to Wheat Productivity: A Case from the Punjab of Pakistan
J. Hartell, M. Smale, P.W. Heisey, and B. Senauer

97-02 The Maize Seed Industries of Brazil and Mexico: Past Performance, Current Issues, and Future Prospects
M.A. López-Pereira and Joao Carlos Garcia

97-03 Farmers' Use of Improved Seed Selection Practices in Mexican Maize: Evidence and Issues from the Sierra de Santa Marta
E. Rice, M. Smale, and J.L. Blanco

97-04 Towards Reduced Pesticide Use for Cereal Crops in Asia
P.L. Pingali and R.V. Gerpacio

97-05 Organization and Performance of National Maize Seed Industries: A New Institutionalist Perspective
M.L. Morris and M. Smale

CIMMYT Research Report

No. 4 Maize Technology in Malawi: A Green Revolution in the Making?
P.W. Heisey and M. Smale

CIMMYT World Wheat Facts and Trends

Supplement, 1995
Ongoing Research at CIMMYT: Understanding Wheat Genetic Diversity and International Flows of Genetic Resources

CIMMYT World Wheat Facts and Trends, 1995/96
Understanding Global Trends in the Use of Wheat Genetic Diversity and International Flows of Wheat Genetic Resources