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**Policy Options to Accelerate Variety Change among  
Smallholder Farmers in South Asia and Africa South  
of the Sahara**

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## Contents

Abstract	v
Acknowledgements	vi
1 Introduction	1
2 Background: Understanding Varietal Turnover	5
3 Policy Options to Accelerate Varietal Turnover	21
4 A Sequencing of Policy Reforms	49
5 Concluding Remarks	52
References	54

## Tables

2.1 A typology of seed marketing systems, industry stage of development, and crops	8
2.2 Average variety ages for selected countries, crops, years, and weights	17
3.1 Selected indicators on varietal registration procedures from the World Bank/IFC <i>Enabling the Business of Agriculture 2016</i>	25
3.2 Selected indicators on seed quality assurance procedures from the World Bank/IFC <i>Enabling the Business of Agriculture 2016</i>	33
3.3 Selected indicators on genetic resources policy and intellectual property rights from the World Bank/IFC <i>Enabling the Business of Agriculture 2016</i>	35

## ABSTRACT

The genetic improvement of food staple crops cultivated by small-scale farmers is a well-established route to increasing agricultural productivity and improving rural livelihoods. But in developing countries where seed markets are commercially active or advancing in that direction, undue emphasis in both policy and research is often placed on the adoption of improved cultivars rather than varietal turnover, or the replacement of an already improved variety with a more recently released improved variety. Strong and consistent rates of varietal turnover contribute to sustaining yield gains over time, protecting those gains from both biotic and abiotic stresses, increasing the sustainability of intensive cropping systems, and improving the quality of the commodity itself for storage, processing, and consumption. This paper explores the importance of varietal turnover in advanced and transitional seed systems for food staples in South Asia and Africa south of the Sahara. We first review the measurement of varietal turnover over spatial and temporal dimensions before examining evidence on policies designed to accelerate varietal turnover rates. We then suggest a sequence of regulatory reforms and public investments designed to accelerate varietal turnover while drawing attention to the economic trade-offs, unintended consequences, and operational challenges of such reforms and investments.

**Keywords: modern varieties, varietal turnover, seed systems, food staples, agricultural input subsidy programs**

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# 1 INTRODUCTION

For many developing countries, technical change in agriculture has been a key contributor to productivity improvement and broader efforts to promote economic growth and poverty reduction (Johnston and Mellor 1961; Schultz 1968; Hayami and Ruttan 1971; Binswanger and von Braun 1991, 1991). While technical change comes in many forms, changes that result from the steady introduction of genetically improved crop varieties<sup>1</sup>—and the scientific investments required to develop such varieties—have been central to this historical narrative (see, for example, Lipton with Longhurst 1989).

The genetic improvement of food staple crops is estimated to account for 20 to 50 percent of the yield growth experienced in developing countries between 1960 and 2000 (Evenson and Gollin 2003). For that reason alone, much has been written on the role and contribution of national development policies and public investments in agricultural research and development (R&D) in support of variety improvement programs (Alston, Norton, and Pardey 1995; Alston, Pardey, and Smith 1999). There is a strong empirical case for such investments given their high social rates of return (for example, Fan and Pardey 1997; Fan 2000; Fan, Hazell, and Thorat 2000).

Yet R&D in support of variety improvement is a necessary but insufficient means of effecting technical change for several well-known reasons. First, successful variety improvement does not ensure widespread adoption by the intended users. Rather, adoption depends on the complex interaction between supply- and demand-related factors for seed, complementary inputs, credit, and the commodity that is ultimately harvested for consumption or sale. Market uncertainty and the low or variable incomes of smallholder farmers in developing countries pose particular challenges in this context.<sup>2</sup> Abrupt policy shifts that affect input-to-output price ratios, the transaction costs associated with purchasing seed or

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<sup>1</sup> Unless otherwise specified, we use the term “variety” to simply denote all cultivated crop varieties (also referred to in the literature as “cultivars”) irrespective of the crop reproductive biology associated with varietal improvement or seed production. This includes self-pollinating and cross-pollinating crops, asexually or vegetatively propagated crops, and hybrids.

<sup>2</sup> An immense body of empirical work exists on the adoption of improved varieties beginning with that of Rogers (1983) and Griliches (1957) in the United States, followed by paradigms developed to explain the Green Revolution, summarized in Feder, Just, and Zilberman (1985), Feder and Umali (1993), and more recently, Sunding and Zilberman (2001), Foster and Rosenzweig (2010), and Jack (2013).

marketing surplus crop output, or any number of other variables can accelerate, slow, or disrupt adoption rates.<sup>3</sup>

Second, in our most well-known model of variety-based technical change—the Green Revolution in South Asia—sustained productivity growth resulted not only from the adoption of improved semi-dwarf) varieties of rice and wheat but also from greater use of fertilizer, pesticides, and recommended agronomic practices, and from major public investments in irrigation, roads, input subsidies, marketing systems, price support mechanisms, and land reforms (Hazell 2010). In retrospect, attributing the region’s food security improvements to improved varieties has proven difficult, and scholars and policymakers are in general agreement that the combined effects of technical change and public policy made the difference.

Third, and the focus of this paper, is that the initial adoption of an improved variety does not guarantee a continuous process of varietal turnover in subsequent periods. In the literature, varietal turnover is defined as the replacement by farmers of an improved variety with a more recently developed improved variety, a process that entails a genetic change. Strong and consistent rates of varietal turnover are needed to sustain yield gains over time, to protect such gains from both biotic and abiotic stresses, to improve the crop’s use of scarce natural resources such as soil nutrients and water, and to improve the quality of output for storage, processing, and consumption.

But the conditions under which farmers continuously replace one improved variety with another are constrained by several factors. For example, farmers who may have adopted improved varieties based on large and observable yield gains may not necessarily adopt subsequently released varieties that offer more incremental and less observable gains. Similarly, farmers who have limited access to seed markets or credit facilities may forgo purchases of a newly released variety and recycle the seed of an adopted variety, as might farmers who are strongly risk averse and require more complete information about the variety’s quality or performance. Farmers’ decisions may also be shaped by what seed companies make

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<sup>3</sup> Note that the term “varietal adoption rate” can be defined in several ways, including the percentage of farmers growing a variety and the percentage of crop area planted to a variety. At a national scale, the second definition is more closely correlated with total seed quantities demanded and thus is often preferred for policy decisions. At a farm scale, in early stages of adoption or variety change, the percentage of farmers adopting lends insights into popularity.

available in the market, and under certain industry conditions, such companies may be incentivized to market older rather than newer varieties. Relatedly, farmers' decisions may be influenced by policies and regulations that affect the availability, cost, and quality of seed made available to them through market and nonmarket channels.

These constraining factors are important where the optimal rate of varietal turnover from society's perspective diverges from the optimal rate from the viewpoints of individual farmers or private seed companies. For example, society may place a greater value on preventing a plant disease epidemic than the individual farmer who expects high returns in the short term from continued cultivation of a susceptible, but still disease-free, variety (Heisey et al. 1997). Meanwhile, private seed companies may place value on selling the largest possible quantities of certified seed each season at the best price possible, even if it means selling varieties that farmers know and trust rather than selling their newest but not-yet-popularized varieties. These examples underscore the necessary role of public policy in addressing such divergences.

With these points in mind, this paper aims to address growing concerns over reportedly slow rates of varietal turnover in food staples grown in many developing countries, and the potential impact that those rates may have on efforts to enhance agricultural productivity. The paper draws on a broad literature to (1) illustrate why varietal turnover matters, how it is measured, and what the empirical record suggests about the impacts of varietal turnover; (2) articulate the trade-offs associated with alternative policy, regulatory, and investment options for accelerating varietal turnover rates in developing-country agriculture; (3) explore the relative effectiveness of those options in achieving such outcomes; and (4) propose a sequence in which such options might be implemented. Emphasis is placed on varietal registration procedures, quality assurance regulations, early-generation seed provision, input subsidy programs, seed enterprises' marketing capabilities, and antitrust policy.

The analytical issues and policy options we examine are inherently specific to each country, market, and crop—no single set of generalizable solutions exists. Given the extensive variation this might pose for our analysis, we focus on emerging or mature seed systems in developing countries that combine

public- and private-sector provision of improved varieties or hybrids of self- and cross-pollinating cereals cultivated by small-scale farmers in South Asia and Africa south of the Sahara. Varietal turnover has far less significance in nascent seed systems where little adoption of improved varieties has occurred and where farmers themselves are the primary source of seed. We discuss a more detailed typology of where varietal turnover matters—for which countries, markets, and crops—below.

The paper is structured as follows. Section 2 summarizes why and where varietal turnover matters, the ways in which it is measured, and analytical insights from prior efforts to measure turnover. Section 3 examines the evidence on policy and regulatory mechanisms for accelerating varietal turnover, highlighting the pros and cons of each. Section 4 discusses feasible reform options and sequencing strategies for developing-country governments, the donor community, and other seed system stakeholders to consider. Concluding remarks are offered in Section 5.

## 2 BACKGROUND: UNDERSTANDING VARIETAL TURNOVER

### **Why does varietal turnover matter?**

Farmers replace seed either to ensure the physical or genetic quality of the same variety or to obtain improved genetic attributes in a new and different variety. Here, we are concerned only with the latter—varietal change associated with improved genetics. Plant breeders have long emphasized the importance of varietal turnover as a means of protecting yield from the evolution of plant disease and sustaining yield gains over time in modern farming systems (Apple 1977; Plucknett and Smith 1986). Don Duvick, a maize breeder, described the rate of varietal turnover as “genetic diversity in time,” or a strategy to reduce vulnerability to plant disease epidemics (Duvick 1984).

Studies in the economics of varietal turnover by Heisey (1990), Brennan and Byerlee (1991), and Heisey and Brennan (1991) were among the first to raise concern about the slow replacement of first-generation semi-dwarf wheat varieties by second-generation varieties during and after the Green Revolution period. These studies drew attention to the importance of comparing the rate of varietal turnover (which Brennan and Byerlee [1991] call “replacement”) with the expected longevity of disease resistance in varieties as a means of diagnosing the vulnerability of a crop to disease epidemics. They also led researchers to explore the relationship between varietal turnover, on the one hand, and yield and yield variability, on the other hand (for example, Hartell et al. 1998; Smale et al. 1998, 2008; Jin et al. 2002; Meng and Brennan 2009). Across a crop-producing region, the average speed of varietal turnover was hypothesized to be positively related to crop productivity; variety age in farmers’ fields was thought to negatively affect yields and contribute to variability. Economists have also emphasized the importance of varietal turnover as a means of demonstrating the high returns to public investment in crop improvement (Alston et al. 2000; Day-Rubenstein et al. 2005; Walker and Alwang 2015).

### **Where does varietal turnover matter?**

When we turn our attention to the question of where varietal turnover matters in developing-country agriculture, we tend to focus on (1) cropping systems dominated by varieties developed by plant-breeding

programs; (2) seed systems that can supply seed of consistent quality that farmers can generally rely on; and (3) farmers who replace seed regularly with the objective of raising yields, protecting yields, or improving grain or fodder quality through traits targeted by plant-breeding programs. These characteristics correlate with a seed sector in an “expansion” or “maturity” phase, which Morris, Rusike, and Smale (1998) characterize as generally commercially oriented, primarily reliant on either improved varieties or hybrids, and dependent on frequent if not annual seed procurement by farmers. The locus of R&D—the source of genetic improvement—in these sectors is often a combination of public organizations and private companies, while seed production systems similarly rely on private companies, contract farmers, or public organizations, or a combination thereof, and regulatory systems govern the type and nature of private investment. Selected niches of the seed sectors in countries as diverse as Bangladesh, India, Pakistan, Kenya, the Philippines, Thailand, South Africa, and Zambia have evolved rapidly toward the maturity phase.<sup>4</sup>

This evolution is typically demonstrated with reference to the niche for maize seed—the singular focus of Morris (1998). But maize is often the exception to the rule. Maize has historically attracted significant levels of private investment in research, production, and marketing primarily due to the unique biological and economic characteristics of heterosis, or the weakly heritable increase in yield that results from the crossing of distinct parental lines.<sup>5</sup>

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<sup>4</sup> See Napasintuwong (2014) on Thailand, Rana (2014) on Pakistan, and Spielman et al. (2014) on India, among others, for recent descriptions of these systems, as well as the many policy and regulatory challenges associated with seed industry growth.

<sup>5</sup> The productive and economic value conferred by heterosis is generally present only in the first generation (F1) of hybrid seed, thus requiring farmers to purchase new F1 seed each season. The terms of trade under which seed is bought and sold determine how this value is distributed between breeders and farmers. As long as the breeder (or seed company) can protect his or her hybrid from imitation by competitors, then the hybrid maize’s reproductive biology provides a means of appropriating a share of the gains from innovation and recouping investments in breeding. This differs from the case for many other crops where improvements resulting from breeding are more stable across generations such that the breeder’s economic incentive dissipates as farmers save harvested grain for use as seed in subsequent seasons, thereby allowing them to appropriate a larger share of the returns to breeding investments without significant remuneration to the breeder beyond the initial purchase of seed. This simple difference in reproductive biology and economic incentives has driven substantial investment in maize improvement in both industrialized and developing countries (Byerlee and Eicher 1997; Morris 1998; Morris, Rusike, and Smale 1998; Pal, Singh, and Morris 1998; Fernandez-Cornejo 2004). The estimated value of the global market for maize seeds and traits was approximately \$10 to \$12 billion in 2012, with the associated spending on R&D ranging from \$1 to \$4 billion (Fuglie et al. 2011; Bonny 2014). These figures are far greater than those for any other food staple crop. And while hybrids of sorghum, pearl millet, cotton, rice, and many vegetable crops exist, the incentives to private R&D are small when compared to maize.

For many other cross-pollinating and self-pollinating crops, these unique characteristics are not observed, making the commercial development of vibrant seed markets more challenging. In some cropping systems based on self-pollinating cereals, the relative importance of farmer seed saving and exchange, even for improved varieties (for example, rice and wheat), may explain slow progress in raising rates of varietal turnover. In other cropping systems based on crops with similar reproductive systems and characterized by vertically integrated supply chains directed toward domestic manufacturing or export markets (for example, cotton), farmers may be rewarded for uniform, quality products and, seeking to meet market standards, may purchase seed regularly from a trusted source in the formal system. Thus, it can be argued that the most effective route for supplying seed to farmers depends on the plant's reproduction system, the economic incentives associated with its reproductive biology, and the broader production and marketing system in which the crop is cultivated.

In Table 2.1, we adapt and revise a simple typology from Smale, Minot, and Horna (2007) that may be helpful in identifying crops and countries that allow us to explore how policy options affect varietal turnover. Among the various types of seed marketing systems, the “best-fit” systems for testing policy options to accelerate varietal turnover are clearly the advanced, privately managed systems (type 2) that supply hybrids or improved varieties of cross-pollinating crops, vegetables, or industrial crops in vertically integrated product channels. However, many of the seed industries in South Asia and most in Africa south of the Sahara are transitional—combining elements of formal, state-managed systems and formal, privately managed systems—and contain elements that similarly lend themselves to testing policy options (type 3). A less promising fit for testing policy options may be the nascent systems that supply seed of self-pollinating food crops, minor food crops, and vegetatively propagated crops almost exclusively through state-managed systems with ad hoc or occasional introductions of new varieties (type 1). A seed system with significant, periodic infusions of emergency seed in times of crisis (type 4) would also be inappropriate.

**Table 2.1 A typology of seed marketing systems, industry stage of development, and crops**

Type of seed marketing system	Characteristics of farmer seed demand	Seed industry stage	Most common types of crops/seed
Nascent: Formal sector, state-managed systems	Limited demand due to either limited potential or actual commercial demand for seed; chronic seed insecurity; irregular seed replacement and variety change	Nascent, small-scale, traditional	Seed for open- or self-pollinated food crops; seed for minor food crops; planting materials for vegetatively propagated crops
Advanced: Formal sector, privately managed systems	Well-articulated demand; high seed security; regular seed replacement and variety change	Advanced, mature	Seed for hybridized crops; improved OPV seed of cross-pollinated crops; seed for vegetable and horticultural crops; seed for industrial crops
Transitional: Formal sector, mixed public and private systems	Ineffective, latent demand; variable degrees of seed insecurity; irregular seed replacement and variety change	Both nascent and expanding; often socially managed	Mixture of crops/seed types in types 1 and 2
Crisis: Emergency seed distribution	Acute seed insecurity, loss of production inputs; involuntary and inconsistent seed replacement and variety change	Nascent, small-scale, traditional, and prone to shocks	Seed for basic staple crops

Source: Authors, adapted from Smale, Minot, and Horna (2007, 75).

Note: OPV = open-pollinated variety.

We might consider other configurations of public and private provision of information, R&D, and seed production than the advanced or transitional types described above. For instance, we could highlight the role and extent of the informal seed system and its integration with the formal system. As Louwaars, de Boef, and Edeme (2013, 191) point out, the linear conceptualization of seed industry development is built largely around stylized experiences with maize, and it has a significant “blind spot” when it comes to important opportunities in the informal sector, leading to ineffective incentives and regulatory frameworks that may serve as obstacles rather than instruments of development (see also Coomes et al. 2015; de Boef et al. 2010; and Almekinders and Louwaars 2002).<sup>6</sup> We might also consider including a category of seed marketing system that might be called the “socially managed seed system” or the “developmental seed system.” We can think of a socially managed system as a subcategory of a state-managed system in that it involves not only the general goal of increasing the provision of seed to farmers but also the more explicit goals of (1) targeting poorer farmers with improved varieties, and (2) ensuring national food self-sufficiency as a less costly alternative to massive food imports. Examples of this include Zambia and Malawi and their input subsidy programs, or Ethiopia, where an extensive state-run seed supply system closely manages private-sector participation (also discussed in detail later). But irrespective of the classification criteria or country typology, our inquiry intentionally limits its scope to allow for in-depth analysis of explicit policy, regulatory, and investment options available to all or most countries that host advanced or transitional seed marketing systems.

<sup>6</sup> Further, for many crops and countries with nascent seed industries, improved varieties have been introduced to farmers periodically over many years but not regularly replaced, so that the varieties farmers consider their own are actually genetic mixtures of improved and landrace materials. Enhancing options to accelerate variety change in such systems is also crucial for food security, although these do not conform to our definition because initial adoption remains a constraint and it is likely that farmers are not regular purchasers of seed.

### ***How do we measure varietal turnover?***

The characterization of a given variety as “new” or “old” can be arbitrary (Johnson and Gustavson 1963; Brennan 1984). For this reason, researchers have proposed several precise definitions that measure rates of varietal turnover. For example, Brennan and Byerlee (1991) proposed an indicator called the (area)-weighted average variety age (WA or WAVA). For a given year, the WAVA is computed as

$$WAVA_t = \sum_i p_{it} R_{it}, \quad (1)$$

where  $p_{it}$  is the proportion of the crop’s area cultivated in variety  $i$  in year  $t$ , and  $R$  is the number of years at time  $t$  since the variety’s release. To calculate the WAVA, the analyst (1) chooses an appropriate geographical unit of observation (farm, village, state, province, nation, region, world) and year (or time series) for analysis; (2) records all varieties grown and the number of years since variety release for each; and (3) calculates the sum over all varieties of the product of the number of years since variety release and the area share planted to the variety, for each observation of year and geographical unit. The WAVA can also be calculated using production weights, that is, the quantity of seed produced for variety  $i$  by all seed producers in an appropriate geographical unit of observation.

Unfortunately, given its construction, the WAVA does not enable us to separate the concept of temporal diversity (expressed in the distribution of variety ages) from that of spatial diversity (reflected in the distribution of variety area shares or production shares). Spatial diversity, or the distribution of varieties across a crop-producing landscape, strongly affects susceptibility to biotic and abiotic stress. The way that varieties grown by farmers are spatially distributed across the area of a crop-producing region is likely to differ significantly depending on the breeding strategy—such as breeding for agroecological niches to improve yield and other performance characteristics, as compared to breeding for broadly adapted mega-varieties. Importantly, some policies may be more successful in influencing spatial distributions of varieties in a crop-producing region as compared to their average variety age.

For this reason, researchers have also used separate measures to differentiate temporal and spatial concepts. For example, average variety age (AVA) expresses the rate of variety change without assigning area or production weights:

$$AVA_t = \sum_i R_{it} \quad (2)$$

In the ecological literature, spatial indexes such as the Simpson, Shannon, Berger-Parker and Margalef indexes express concepts of richness and proportions of relative abundance, and are measured in terms of population sizes and species counts (Magurran 1988). The same indices can be used to capture varietal concentration in a given market or geography. Consider, for example, the Herfindahl-Hirschman Index (HHI). Typically used to measure the share of a market held by firms operating in a given industry, the HHI is an index that can capture varietal concentration in a given market. Specifically, an HHI can measure a variety's position in relation to the total population of varieties under cultivation or in production at any one point in time, and is calculated as the sum of the squared market share (in percentage terms) of each variety in cultivation or production for a given period. If measured over time, like other spatial indices, the HHI contributes both spatial and temporal information. By tracking index values over time, it is possible to discern changes in the prevalence of a given variety and its replacement by other varieties.

Formally, the HHI (time series) is given as

$$HHI_t = \sum_{i=1}^n s_{it}^2, \quad (3)$$

where  $s_{it}$  denotes the share of the  $i^{th}$  variety of  $N$  varieties in cultivation or production at time  $t$ . Index values between 1,500 and 2,500 indicate moderate concentration, and index values greater than 2,500 indicate high concentration. The maximum index value is 10,000 and denotes only one variety in cultivation or production. By tracking index values over time, it is possible to discern changes in the prevalence of a given variety and its replacement by other varieties.

However, all of these measures of varietal turnover have shortcomings. First, they depend on the accuracy of the variety name, release date, and area or production estimates, and the completeness of the variety list or register. Second, calculations based on area weights are feasible only if data used to calculate variety-specific areas under cultivation are statistically representative and accurately reported. Whether the data are extracted from expert opinion surveys, national statistics, remote sensing, or surveys

of farm households, nontrivial concerns exist over inaccurate recording or recollection of variety names, nonresponse bias, and other issues.

Third, turnover measures based on production weights are feasible only if variety-specific seed production quantities are fully and accurately disclosed, which in a competitive market may constitute proprietary information from a seed company's perspective. Moreover, they do not paint a complete picture of varietal turnover if they account for only that share of seed use that is supplied by the formal market for which production quantities are disclosed. This means that calculations may overlook varieties that are saved or exchanged locally, suggesting the possibility for downward bias in calculating average variety age. That said, production weighting can address the potential bias introduced by inaccurate or missing responses to questions about variety names asked in farmer surveys that are designed to provide the necessary data for area weighting.

Fourth, it is important to recognize that turnover measures are not immediately comparable across crop, time, and cropping system. A set of indexes that measures different dimensions of varietal turnover—at different nodes in the supply chain—could be more useful in pinpointing problems and highlighting potential policy trade-offs. Clearly, turnover measures are relevant only when viewed in the wider context of the overall adoption rate for improved varieties in a given geography. Turnover measures have little meaning for policy where adoption rates are low because the measures reflect the practices of a minority of farmers. Without a meaningful rate of variety adoption (for example, if the national cropped area planted to improved materials is only 10 percent or less), accelerating varietal turnover is unlikely to have much of an impact on national productivity. In addition, a set of indices that measures different dimensions of varietal turnover—at different nodes in the supply chain—could be more useful in pinpointing problems and highlighting potential policy tradeoffs.

Finally, turnover measures should be viewed in the wider context of a modern variety's "life cycle," which consists of three periods with different cost and benefit structures. The first period is the *time to variety release* and includes only the investment costs of R&D and the regulatory compliance costs associated with variety release procedures. This first period generates no benefits. The second

period is the *time to adoption*, or the additional time lag that follows variety release in which there may be no further investment costs but also no benefits from investing. The third period is the time in the field—*the duration of adoption* or *variety longevity*—when benefits accrue but investment costs have ceased. Costs in this period involve seed production, maintenance of breeder seed, costs of meeting seed quality assurance regulations, marketing, and compliance or monitoring costs related to any other regulations. Our turnover measures abstract from the first period (although we recognize the importance of a more in-depth treatment of the role played by crop breeding programs and R&D investment in accelerating varietal turnover) and instead focus on the second and third periods. Note that in advanced seed markets, the second period tends to zero—that is, there is no meaningful time lag between the release of a new variety and its adoption. However, in more transitional seed markets, this lag is often nontrivial and does need to be considered in the design of policies and regulations that aim to accelerate varietal turnover. Put another way, in comparisons between countries and crops where these lags are considerable, turnover measures may systematically underestimate the age of a variety by failing to incorporate the regulatory delays associated with release. And omitting these R&D lags likely ignores some key policy levers for accelerating varietal turnover.

In sum, even with the best measures available, there are significant limitations to capturing the extent of a variety's diffusion, the spatial and temporal patterns of diffusion, and the contribution of various nodes of the seed value chain to that diffusion. Moreover, it is not always clear why some farmers might want to replace improved varieties with newer varieties on a regular basis, and why other farmers may choose to stick with the varieties they are already cultivating.

### **What does the empirical evidence on varietal turnover indicate?**

But in the absence of indicators that perfectly measure the multiple dimensions of varietal turnover at different nodes in the supply chain, the indicators described above are a useful departure point to explore the empirical evidence on varietal turnover rates. We begin with a brief review of work conducted by the

International Maize and Wheat Improvement Center (CIMMYT) starting in the late 1980s, and follow that with more recent examples where WAVAs have been used to inform policy and investment priorities.

During the late 1980s, CIMMYT was concerned with the susceptibility of modern wheat varieties to rust diseases and the slow rate of replacement of wheat varieties after the Green Revolution in Pakistan, especially when compared with the Yaqui Valley in Mexico and the Punjab of India. This was highlighted in a study by Heisey (1990) that examined these dynamics of varietal replacement and spatial diversification in Pakistan's Punjab province. It concluded that varietal replacement has been slower than a "reasonable target" (once every five to six years, with optimal turnover of four years) and that more than 50 percent of the wheat area was planted to susceptible varieties. The report also found a notable mismatch in the market: while the Punjab Seed Corporation, a state-run seed enterprise, sought to market certified seed (that is, promote seed replacement) to farmers rather than facilitate variety change (that is, promote varietal turnover), farmers tended to purchase seed for the purposes of varietal turnover and relied on other farmers for seed replacement.

Heisey and Brennan (1991) then developed an analytical model of the demand for replacement seed, depicting the economically optimal rate of varietal turnover and applying it to wheat seed demand in Pakistan. They posited that the optimal decision to replace wheat seed for the purposes of varietal change is jointly determined by a number of factors, including the rate of gain in yield potential of new varieties, the rate of depreciation of retained seed, farmer learning, and seed and capital costs, as well as parameters related to the probability of loss of effective resistance, such as the rate of mutation of disease organisms, the structure of genetic resistance to disease in a variety (for example, based on single genes or multiple genes), and the growing environment.

CIMMYT's experience with calculating WAVAs for wheat illustrates how varietal turnover rates vary widely from temporal and spatial perspectives. For example, Brennan and Byerlee (1991) compared WAVAs for the 1970s–1980s among the Punjabs of Pakistan and India, the Yaqui Valley of Mexico, and wheat environments in Australia, the United States, Argentina, and Brazil. WAVAs ranged from a mean of 3.1 (in the Yaqui Valley, the testing ground of CIMMYT wheats with heavy disease pressure) to 11.1

(in Pakistan's Punjab), while the rate of varietal turnover was declining during the period of study. They argued that this trend partly reflected a "return to normality" after the introduction of semi-dwarf wheats, and expressed concern that the WAVAs in certain environments were greater than the expected longevity of resistance to wheat rusts. Later, using provincewide data for a longer time period, Hartell et al. (1998) similarly found that the WAVA had increased over time in the Punjab of Pakistan, rising to nearly 11 years. Interestingly, these findings have not necessarily held out over time: in a recent study of wheat variety adoption in the same province, Nazli and Smale (2015) found an AVA of eight to nine years, and shortly after that study, it was observed that the most popular variety grown by farmers surveyed, Seher-06, succumbed to rust and was rapidly replaced by other varieties.

Following the work by Heisey (1990), Brennan and Byerlee (1991), and Heisey and Brennan (1991), the WAVA was applied in many of the global, regional, and farm impact analyses. A study that used data from CIMMYT Global Wheat Impacts Surveys in 1990 and 1997 reported an average WAVA of 12 in both years for all spring bread wheat varieties released by national programs and grown in 37 countries around the developing world (Smale et al. 2002). In their in-depth analysis of the same data, Heisey, Lantican, and Dubin (1998) concluded that varietal turnover rates did not improve from 1990 to 1997 for seven countries in Africa south of the Sahara. Most estimated WAVAs fell in the range of 10 to 16 years.

Recently, Walker and Alwang (2015) applied the concept (which they termed as the "velocity" of varietal turnover) in a comprehensive study of multiple crops and countries in Africa south of the Sahara. Their summary of findings from 117 crop-by-country combinations in Africa South of the Sahara estimated an overall average WAVA of 14 years across crops, with a range from 10 to 20 years across crops. The lowest WAVAs were found for banana and sweet potato (vegetatively propagated crops), which they explained by the absence of earlier research or releases in the 1980s and 1990s. They further

concluded that the rate of varietal turnover varied widely by crop reproduction system, time period of study, plant disease pressure, and market demand for product characteristics.<sup>7</sup>

Walker and Alwang (2015) suggest that in addition to the overall adoption rate, an average varietal age *under* 10 years signals progress in plant breeding from an economics perspective, while a WAVA approaching 20 years implies that recent releases are not competing well with older products. Pairing high adoption rates and high varietal turnover rates as signals of successful crop improvement programs, they found that only 16 of the 117 combinations had both above-average adoption rates (greater than 35.5 percent, area-weighted) and high varietal turnover rates (less than 10 years, against an area-weighted average of 14 years). These included larger-area programs in maize, cassava, and cowpea and some smaller programs in soybean and rice. The authors also noted the similar results for hybrids in eastern and southern Africa compared to improved open-pollinated varieties in West and Central Africa. One caveat is that not all 1,145 varieties included in the database had variety release information, so there is potential for measurement error.

Disappointingly, Walker and Alwang (2015) found that the vintage of maize and wheat varieties in farmers' fields had not changed meaningfully in Africa south of the Sahara during the past 14 years. They estimated the WAVA for maize at 13 years throughout Africa south of the Sahara. Smale and Olwande (2014) found a WAVA of 17 years for all hybrids and improved varieties of maize (9 percent of which were hybrids) grown by farmers in the major maize-growing areas of Kenya in 2010 (Smale and Olwande 2014). Initially, Kenya had adoption rates that rivalled those of the US Corn Belt in the 1930s and 1940s (Gerhart 1975), and the adoption rate calculated from the same data source was 82 percent of farmers. The results reported by Smale and Olwande (2014) suggest a much lower WAVA than that reported by Hassan in 1998 (23 years). That said, Walker and Alwang (2015) cite even lower varietal turnover rates for irrigated rice in South Asia (Pandey et al. [2015] in the same volume). Dryland crops in South Asia also fall in a similar range to those reported for Africa south of the Sahara (10 to 20 years),

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<sup>7</sup> Interestingly, the outlier in the calculation of varietal turnover is the Russet Burbank potato in North America, with an average age of 40 to 50 years.

with the noteworthy exception of pearl millet—where hybrid turnover is driven by downy mildew disease (Charyulu et al. [2015] in the same volume). Once again, this illustrates the sensitivity of the WAVA to the time period and observational unit.

Table 2.2 summarizes the WAVAs recently calculated for several other crops, geographies, periods, and farm sizes. These figures similarly suggest the sensitivity of the WAVA to time period and observational unit. Nonetheless, several interesting observations are worth noting. First, findings from earlier studies of wheat variety age in India seem to find continued support in these recent calculations. Although production weights are not necessarily the first-best measure of average variety age, the figures for all India in Table 2.2 indicate that the production-weighted average age has increased significantly from 9.4 years in 1997/1998 to 2001/2002 to 13.2 years in 2006/2007 to 2009/2010. Among other possibilities, this suggests shortcomings in the public seed supply system that underpins varietal turnover for Indian wheat (Krishna et al. 2016).

**Table 2.2 Average variety ages for selected countries, crops, years, and weights**

Country	Crop	Reference year	Average variety age (years)	Weight
<b>Bangladesh<sup>a</sup></b>				
Overall	Rice	2011/12	20.01	Area
Marginal farm size	Rice	2011/12	20.75	Area
Small farm size	Rice	2011/12	20.24	Area
Medium farm size	Rice	2011/12	20.29	Area
Large farm size	Rice	2011/12	19.20	Area
<b>India (Haryana)<sup>b</sup></b>				
Overall	Wheat	2009/10	9.74	Area
Marginal farm size	Wheat	2009/10	10.11	Area
Small farm size	Wheat	2009/10	10.32	Area
Medium farm size	Wheat	2009/10	9.45	Area
Large farm size	Wheat	2009/10	6.93	Area
<b>India<sup>c</sup></b>				
1997/98 to 2001/02	Wheat	n/a	9.4	Production
2006/07 to 2009/10	Wheat	n/a	13.2	Production
<b>Pakistan<sup>d</sup></b>				
Overall	Wheat	2011/12	7.03	Area
Overall	Rice	2011/12	6.25	Area
Overall	Cotton	2011/12	2.22	Area
<b>Ethiopia</b>				
Overall <sup>e</sup>	Teff	2010/11	16.0	Production
Overall <sup>f</sup>	OPV maize	2013/14	17.7	Area
Overall	Hybrid maize	2013/14	10.6	Area
Overall	Bread wheat	2009	13.9	Production
Overall	Sorghum	2009	9.9	Production
<b>Kenya<sup>f</sup></b>				
Overall	OPV maize	2013/14	12.4	Area
Overall	Hybrid maize	2013/14	13.7	Area
<b>Zambia<sup>f</sup></b>				
Overall	OPV maize	2013/14	13.5	Area
Overall	Hybrid maize	2013/14	12.8	Area
<b>Ghana<sup>f</sup></b>				
Overall	OPV maize	2013/14	24.0	Area
Overall	Hybrid maize	2013/14	6.0	Area

<sup>a</sup> Source: Naher and Spielman (2015) based on data from Ahmed (2013). Average age denotes share of all rice-cultivated area planted to the top-five varieties only; “marginal” farmers cultivate less than 0.2 hectares (ha); “small” between 0.2 and 0.6 ha; “medium” between 0.6 and 1.0 ha; and “large” greater than 1 ha. <sup>b</sup> Source: Krishna et al. (2016). “Marginal” farmers cultivate less than 1 ha; “small” between 1 and 2 ha; “medium” between 2 and 10 ha; and “large” greater than 10 ha. <sup>c</sup> Source: Krishna et al. (2016). Figures denote arithmetic averages of production-weighted average variety age for the top-20 varieties produced in each year. <sup>d</sup> Source: Based on data from IFPRI/IDS (2012). <sup>e</sup> Source: Spielman and Mekonnen (forthcoming). <sup>f</sup> Source: Abate et al. (2017).

Note: n.a. = not applicable; OPV = open-pollinated variety.

Second, findings for wheat variety age in Pakistan are considerably lower than estimates from both previous and recent periods discussed earlier. These differences are likely related to differences in the sampling frames used for the study, with the figures in Table 2.2 drawn from a rural household survey

that did not explicitly sample based on wheat-growing areas or populations. This demonstrates the sensitivity of WAVAs to the type of data used, as described earlier.

Third, the area-weighted average variety ages for rice in Bangladesh and wheat in Haryana, India, show relatively little variation across farm-size categories, suggesting that marginal or small-scale farmers are no less likely to cultivate newer varieties than large-scale farmers. Third, certain crops for which one would expect rapid turnover—crops where extensive R&D investments have been made in genetic improvement such as rice and wheat—are characterized by relatively high average variety ages. This may again imply that recent releases are not competing well with older ones, possibly because foundation seed production and distribution systems are poorly functioning. It may also reflect the adoption problem discussed earlier: despite new and improved variety releases, adoption depends on complex factors relating to market signals for seed, complementary inputs, the commodity that is ultimately harvested for consumption or sale, and the relative wealth or poverty of the households that produce and/or consume the commodity. Or it may imply that seed companies are resistant to incurring the costs of changing their product offerings to farmers.

An illustration of this point is the continued dominance in Kenya of H614, a maize hybrid—a phenomenon that has baffled observers for some time. In Kenya, Smale and Olwande (2014) found that ownership of the hybrid by the Kenya Seed Company (KSC), a state-owned enterprise, had a very strong positive effect on the WAVA of maize hybrids planted by farmers in 2009/2010. H614 is one of KSC's oldest hybrids and is grown in zones where farmers have grown hybrids the longest. In 1992, H614 was planted on 42 percent of national maize area (Hassan 1998). In 1998, CIMMYT data show the same hybrid representing 51 percent of maize area, and in 2010, KSC reported that it still represented 48 percent of seed sales (F. M. Ndambuki, Kenya Seed Company, personal communication, May 11, 2010).<sup>8</sup> Apparently, KSC has had difficulty surpassing the overall performance and popularity of this late-

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<sup>8</sup> Estimates reported by De Groote et al. (2015) indicate 26 percent of area in 2009, though these were based on a sample that probably included areas outside the major maize-growing areas.

maturing hybrid that uniquely suits the growing conditions in Kenya, though numerous hybrids have been developed and released since H614's introduction.

But this explanation is unlikely after 50 years of maize breeding in Kenya. Rather, it is much more likely that the company is not making the costly investments associated with replacing this premier product. Product replacement usually reduces the net returns of seed companies unless they risk losing market share by failing to replace, or unless the new variety has a lower cost of goods. Until very recently, KSC faced no competition in the Kenyan highlands, and new hybrids, which will be three-way or single crosses, are likely to be somewhat more expensive to produce than H614 (Gary Atlin, Bill & Melinda Gates Foundation, personal communication, July 16, 2016).

Ultimately, however, we are interested not in average variety age in isolation but in the relationship between variety age and yield. To that end, researchers have sought to directly test the effects of varietal turnover on yields in farmers' fields using econometric models and an array of the indices described above. With respect to the effect of varietal age on productivity, the evidence appears fairly supportive of the hypothesized positive relationship between variety turnover rates and yield growth, although there are exceptions.

Smale et al. (2008) examined the effects of area-weighted variety age and similarity of parentage on wheat productivity in the Punjab of India during the post-Green Revolution period. They found that slow variety change in farmers' fields partially offset the yield gains from diversification of parentage. A decade earlier, estimating a productivity model for the Punjab of Pakistan, Hartell et al. (1998) found significant, negative effects of variety age on wheat yields, but positive impacts of greater concentration of crop area in fewer varieties in the irrigated areas. In other words, variety age increased yield variability. Jin et al. (2002) found large, statistically robust effects of varietal turnover on total factor productivity across provinces in Chinese wheat farming from 1982 to 1995.<sup>9</sup> Smale and Olwande (2014) explored

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<sup>9</sup> Jin et al. (2009) also explored the determinants of varietal turnover rates in their modeling of Chinese wheat production and found significant effects for yield potential and research investments on varietal turnover in wheat, but they noted different results for rice and maize, which they explain by farmer preferences for quality or nonyield traits in the latter two crops during the time period of study.

similar relationships for maize in Kenya, and find that yields were significantly and negatively correlated with variety release year, suggesting that some older releases (many of which were later-maturing and thus higher-yielding) may still be showing an advantage.

With respect to the effect of spatial dimensions of varietal turnover on productivity, the evidence appears to suggest that spatial distribution often has the strongest effects on yield and yield variability (Smale et al. 2008, 2003; Hartell et al. 1998). Smale et al. (2003) explicitly tested the relationship between spatial and temporal diversity in wheat production systems of Australia and China between 1982 and 1997. Econometric models showed that higher area-weighted average variety age was positively related to spatial diversification. In those instances, older varieties occupied minor shares as farmers gradually replaced them, leading to lower area concentration. In the Australian model, a more rapid rate of variety release and a higher proportion of locally bred material was associated with greater spatial diversification of varieties. In the Chinese model, the effect of market liberalization, as compared to the period of the household reform system, was associated with similar spatial diversification. Moreover, these results suggested a potential trade-off between spatial and temporal diversification as policy goals: they are imperfect substitutes, and the ideal combination of the two likely depends on agroecology and changes over time. These are examples of the inherent complexities of policymaking to accelerate varietal turnover.

### 3 POLICY OPTIONS TO ACCELERATE VARIETAL TURNOVER

This section examines policy options designed to accelerate varietal turnover. We define policy as the laws, regulations, and guidelines as well as the taxes, subsidies, market interventions, and public investments designed and executed by government to achieve some social or economic goal. In the context of developing-country agriculture, we assume that the goal is sustained productivity growth in food staple production.

Each subsection explores a single policy option, beginning with varietal registration procedures and continuing through quality assurance regulations, early-generation seed provision, input subsidy programs, seed enterprises' marketing capabilities, and antitrust policy. The policy option is defined, illustrated, and analyzed in terms of whether it incentivizes farmers to *continuously* replace—and benefit from the replacement of—improved varieties with newer releases. As noted earlier, this is distinct from a policy option that encourages farmers to make a one-off switch from one improved variety to another. Broad conclusions are then drawn around the likelihood that the option will influence varietal turnover either directly or indirectly.

Note that the policy and regulatory options explored here are largely focused on improving the *supply* of improved varieties to accelerate varietal turnover. This should not be viewed as disregard for policy options that encourage greater *demand*. Rather, we address only supply constraints here for the following reasons. First, many of the options discussed below can be readily influenced by public policymakers, policy advisers, and associated organizations in a manner that can directly affect the supply of improved varieties available to farmers.

Second, we assume that such individuals and organizations have better information, stronger foresighting capabilities, and clearer incentives to make policy decisions that address the inherent trade-offs between an optimal rate of varietal turnover from society's perspective and the rate that is economically optimal for an individual farmer or private seed company. In other words, it is the policymakers' job to invest in increasing the availability of new varieties to address a range of challenges

that individuals themselves may not respond to. These may be the evolving threats posed by biotic and abiotic stresses, including those associated with climate change; systemic changes in the economics of farming linked to demographic transitions, income growth, urbanization, and changing consumer diets; or global changes in commodity trading patterns that affect the returns on specific crops and agricultural products.

Third, policies and investments pertaining to demand generation require much more thorough treatment, recognizing that the demand for seeds and traits is derived from demand for the final product and is determined by variables such as weather, seed prices, the price of substitutes (for example, saved seed), the price of complementary inputs (for example, fertilizer), the genetic attributes and physical quality of the seed, and farmers' expectations and preferences for specific traits and varieties. Policies and investments to generate demand for quality seeds and traits are many, and include such examples as strengthening of agricultural extension and advisory services to increase awareness of new varieties through popularization campaigns; providing credit facilities to farmers to encourage seed purchases; and enhancing the informational and financial services provided by input retailers who sell new varieties to farmers. Each deserves separate and detailed treatment.

### **Accelerating varietal registration and release**

A logical starting point for policy reform is to examine the rules and guidelines that govern the release of new varieties (Tripp and Rohrbach 2001; Tripp 1997; Tripp and Louwaars 1997). Here, the logic is that regulatory procedures represent a direct and costly impediment to the release of new varieties and thus increase the total time required to move from development through adoption of varieties that are promising replacements for those already grown by farmers. Concerns tend to revolve around industry-articulated concerns about (1) the crops that are subject to testing under varietal registration rules and guidelines; (2) the time required to conduct tests for distinctness, uniformity, and stability (DUS); (3) the number of seasons and locations required for national performance tests of value in cultivation and use (VCU); (4) the criteria and counterfactuals (the “check” varieties) used to determine VCU; (5) whether

such tests may be conducted by the applicant (that is, a breeder or seed company) itself or whether proprietary germplasm must be handed over for testing to the public regulators or research agencies, the latter of which may constitute potential competitors; and (6) whether registration (and the associated test results) provides a credible signal of genetic quality to farmers.

Varietal registration regulations and procedures were originally designed to ensure that varieties distributed to farmers were superior in their performance to existing varieties on the market, and to prevent the cultivation of varieties that might have a negative impact on the environment or were susceptible to pest and diseases (FAO 2011; Bishaw and van Gastel 2009). Today, however, it might be argued that these regulations and procedures are simply vestiges of systems that were wholly reliant on public breeding programs, in which state-owned seed companies depended on the handoff of improved germplasm from public breeding programs, and VCU and DUS testing procedures were a means of imposing quality controls at this upstream point in the system (for example, Gisselquist et al. 2013). Such regulations may have lost their capacity to generate the social value envisioned in the original regulations, and they may instead be a critical constraint on more rapid release of new varieties to farmers. With the entry of private-sector breeding programs and private seed production and marketing operations in many countries—or seed policies that aim to encourage private-sector entry—the importance of these testing procedures is worth revisiting.

Strict DUS and VCU testing regulations remain in place in many developing countries and for many crops (Setimela, Badu-Apraku, and Mwangi 2009; Langyintuo et al. 2010). But the array of exceptions to testing regulations in many of these same countries indicates the potential for regulatory reform. Exceptions include requiring testing only for publicly developed varieties or publicly developed varieties that are to be promoted or subsidized by public programs; allowing for varieties under development to be tested widely among farmers without prior registration; allowing for voluntary or automatic registration of varieties through simple, low-cost application procedures; and exempting crops that are not central to national food security from strict testing.

Several examples of regulatory reforms are worth noting. Turkey loosened its variety release regulations in 1982 by reducing VCU testing to one to two years and allowing companies to conduct and report on their own tests, and the subsequent decade saw a rapid increase in the number of seed companies doing business in Turkey and the number of field crop and vegetable varieties released on the market (Gisselquist and Pray 1999). Bangladesh, India, Philippines, and Kenya, among others, do not require variety registration or associated testing for many nonstaple crops, while in China and South Africa, registration is automatic and testing is voluntary for most or all crops (see, for example, Goldschagg 2016; Gisselquist 2016; Ar-Rashid, Ali, and Gisselquist 2012). To further accelerate the release of new varieties, countries are also exploring regional harmonization of their registration procedures or mutual recognition of registrations. Recently, Bangladesh, India, and Nepal took steps to address these nontariff barriers by signing an agreement that harmonizes rice varietal registration procedures and mutual recognition of registrations among the countries, paving the way for lower regulatory burdens and more rapid release of improved varieties developed in any of the three countries (IRRI 2014). Agreements along similar lines (but across a wider range of crops) have also been forged among members of the various regional economic communities in Africa south of the Sahara, although actual progress has been slow in reducing national regulatory burdens and accelerating variety releases through regional exchanges of data and material (Herpers et al. 2017). Ultimately, these illustrations suggest that regulations governing varietal registration and release are not singular or monolithic across developing countries. Table 3.1 illustrates this with indicators extracted for selected countries with mature or transitional seed systems from the World Bank Group's (2016) *Enabling the Business of Agriculture* report.

**Table 3.1 Selected indicators on varietal registration procedures from the World Bank/IFC  
Enabling the Business of Agriculture 2016**

Indicator	Ethiopia	Kenya	Tanzania	Zambia	Bangladesh	Nepal	Ghana
Does the country's law establish a variety release committee?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
How often does the legally mandated variety release committee meet in practice?	Yearly	On demand	Twice a year	Twice a year	On demand	Yearly	Does not meet
If there is a legally mandated release committee what is the composition of the committee? (no. of private-, public-sector representatives on the committee)	0, 3	4, 3	3, 11	4, 8	3, 17	4, 11	5, 13
Can a variety be commercialized immediately after the recommendation of the variety release committee?	Yes	Yes	No	No	Yes	No	Yes
Does the country have a variety catalog listing new varieties? Is the variety catalog available online?	Yes, No	Yes, Yes	Yes, No	Yes, Yes	Yes, Yes	Yes, Yes	No, n.a.
How often is the catalogue updated?	Annually	Annually	Annually	Annually	Annually	Annually	No catalog yet n.a.
Does the catalog specify agroecological zones suitable for plantation of each listed variety?	Yes	Yes	Yes	No	Yes	Yes	
Seed registration procedures (no.)	4	6	6	5	2 <sup>a</sup>	5	6
Seed registration time (days)	620	321	333	544	3 <sup>a</sup>	611	757
Seed registration cost (US\$)	488.9	1,798.5	652.1	1,045	0 <sup>b</sup>	0	No data
Seed registration cost as a share of income per capita (%)	88.9	140.5	70.10	59.4	0.0	0.0	No data

Source: World Bank Group (2016).

Note: n.a. = not applicable.

<sup>a</sup> Registration is not available for maize varieties. Private companies can, at their discretion and at no cost, list maize varieties in the national catalog. This is what the procedures and time capture.

<sup>b</sup> Registration is not mandatory, therefore nonmandatory costs are not accounted for here

But despite the regulatory reform space suggested by these exceptions, some analysts still suggest that there is greater scope for regulatory reform but that efforts are impeded by vested interests in the broader political economy (Spielman and Kennedy 2016; Gisselquist et al. 2013). For example, regulatory agencies themselves rarely advocate for reform if those reforms entail disassembling their infrastructure, reducing their staffing, or decreasing their influence. See Rana, Spielman, and Zaidi (2016) for an illustration with Pakistan’s Federal Seed Certification and Registration Department. Similarly, state-owned seed enterprises rarely advocate for reforms if changes in varietal registration procedures allow competitors to enter the market, chip away at an enterprise’s market power, or compromise its overarching social objectives such as improving national seed security. Domestic seed companies may similarly view such procedures as a barrier to entry that protects against foreign competition and from the introduction of foreign varieties that may compete well in local markets. Such may be the case with respect to rice and wheat varieties released in India but not officially released in Bangladesh, resulting in either cross-border seed smuggling or the annual issuance of seed import permits to Bangladeshi companies that opened the door to rent-seeking behavior (D. Gisselquist, personal communication, July 7, 2016).

The reduction or elimination of varietal registration and release procedures is attractive for several reasons. First and foremost, VCU testing in many countries tends to focus simply on a narrow set of criteria (typically yield gains and stress tolerance) without reference or guidance on how to consider other (typically nonyield) attributes—grain quality, taste, or storage and cooking characteristics—despite the potential importance of those attributes to farmers and consumers. Second, VCU testing is typically conducted in comparison with a check variety that may or may not be the most relevant comparator for farmers—or heterogeneous populations of farmers—who ultimately decide to cultivate the variety or not. Third, both DUS and VCU tests can be costly procedures, especially when regulations require extensive duplication in multiple agroecologies for extended periods of time. Fourth, committees mandated to review testing results and recommend (or reject) the release of a variety have come under scrutiny in recent years over concerns about ad hoc decision making, insufficiently frequent meetings, excessive

bureaucracy, intrusion of nonscientific considerations, and insufficient representation of seed industry stakeholders in the decision-making process. Finally, tests are only as useful as the regulatory system's throughput capacity: for crops where new varieties are released every season or every few seasons, multiyear testing procedures can substantially slow the rate of variety release.

This should not be taken to suggest that across-the-board deregulation of seed markets or the abandonment of varietal registration procedures is a desirable or socially beneficial goal in and of itself. To be sure, many of the agricultural policy reforms promoted in developing countries—particularly in Africa—during the 1980s tended to equate market liberalization with seed system deregulation and privatization (Tripp and Rohrbach 2001; Tripp 1997; Tripp and Louwaars 1997). Yet the inherent market failures that characterize seed markets in such countries persisted, causing private companies to shy away from investment and leaving farmers without sufficient access to new varieties.

Varietal registration and testing may still have a place. Varietal registration lists can be a useful source of information for policymakers, seed providers, and even farmers on available traits if such information is detailed and warehoused in a manner that provides broad access. There is also scope for thinking about registration—or more specifically, deregistration—as a mechanism to remove varieties from the market and encourage the distribution and adoption of newer varieties. Deregistration or a notification system that flags obsolete varieties is particularly relevant in cases where specific varieties are identified as susceptible to pest and disease pressures, and where the rapid replacement with less susceptible varieties is deemed critical to food security.

However, experience suggests that deregistration itself does not necessarily remove a variety from production or encourage varietal change. Farmers may retain and exchange seed of a deregistered variety among themselves, and may do so in response to strong variety-specific market signals from consumers such as preferences for taste or cooking quality. Moreover, deregistration or withdrawal of a variety without a credible, ready-for-market successor could lead to economically or socially inferior outcomes relative to, say, a strategy that rewards public or private breeders for developing and distributing newer, better varieties. Relatedly, the costs of implementing a deregistration strategy—

identifying and credibly penalizing farmers who grow the variety or seed producers who multiply it—could exceed the strategy’s benefits.<sup>10</sup>

To illustrate the difficulties in planning and implementing varietal succession strategies, consider Pakistan’s experience with wheat rust during the second half of the Green Revolution. Heisey et al. (1997) showed that there are potential economic trade-offs associated with pursuing a policy goal of reducing expected yield losses from wheat rusts in Pakistan by (a) greater spatial diversification of varieties, (b) use of a temporally changing list of resistant varieties, and (c) promoting more diversified genetic backgrounds in varieties. They found that during the study period (1978–1990), the average yield of recommended varieties in Pakistan’s province of Punjab was similar to that of varieties that had been banned due to wheat rust susceptibility. The tendency for many farmers to grow a few preferred varieties appears to have had greater yield effects than growing banned (as compared to recommended) varieties. In most years (11), maximizing spatial diversification would have resulted in annual yield losses (an average of 65 to 70 kilograms per hectare per year) that cost US\$50 to \$80 million (in constant [1990] terms) during the later years when wheat area in Punjab was concentrated in fewer varieties.

The analysis by Heisey et al. (1997) suggested two obvious reasons why farmers do not choose to grow wheat varieties with the level of rust resistance that would be socially desirable: (1) farmers choose to grow high-yielding varieties irrespective of whether they are known to be susceptible to rust, and (2) farmers choose to grow high-yielding varieties irrespective of whether they have the same basis of genetic

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<sup>10</sup> An alternative to deregistration might be to use negative incentives to discourage companies from producing and marketing specific varieties. Such incentives can take the form of penalties, fines, or taxes on a company that produces an obsolete variety or the withdrawal of subsidies, credit concessions, or other financial arrangements otherwise provided to that company. In theory, the revenue generated or saved from such an approach could be used to offset the social costs associated with continued cultivation of undesirable varieties. For such incentives to work, however, the companies in question must be responsive to financial signals—an assumption that may not hold in the case of state-owned seed enterprises where operating losses are regularly covered by public resources. Moreover, the impact of these incentives depends partly on the extent to which seed companies can pass additional costs on to their farmer-clients, that is, whether demand is inelastic relative to supply. Such may be the case where there are a limited number of seed providers in a given market or where the seed market is characterized by monopolistic competition where producers sell products that are slightly differentiated from one another (for example, by traits, branding, or packaging) and are not perfect substitutes. In such situations, it is possible for a seed company to simply pass on the costs associated with a penalty, fine, tax, or subsidy withdrawal to the farmer. And when the monitoring and enforcement costs of monetary incentives are further considered, the outcome may again be a socially inferior policy that would be a second-best alternative to rewarding seed companies for selling newer, better varieties and to supporting such companies with effective breeding and R&D programs.

resistance as those grown by other farmers. They further noted that while efforts to influence the rate of varietal turnover by adding and removing varieties from a recommended list was the primary tool used by the public research and administrative agencies to protect against the threat of known rust pathogens, the strategy had serious shortcomings. First, recommended lists are imperfect because pathogens evolve and the genetic base of resistance is also modified by plant breeders (that is, varieties can carry different types of resistance), meaning that the resistance threshold at which a variety should be withdrawn from circulation is difficult to ascertain with scientific accuracy. Second, as recalled more recently by Heisey (personal communication, June 16, 2016), recommended variety lists (or, under more extreme circumstances, variety bans) can be the subject of vested interests.<sup>11</sup> Perhaps most important for this review, Heisey (personal communication, June 16, 2016) argued that banning varieties was just not very effective because farmers sourced seed from other farmers or from their own saved seed—until they lost their crop to wheat rusts. They continued to grow banned varieties because the disease-free yield of many of them was higher than that of the varieties that were meant to replace them.

In summary, there is likely considerable potential in accelerating varietal turnover—or at least accelerating the number of varieties available to farmers—by reducing the regulatory burdens associated with varietal registration. Low-cost and readily implementable regulatory reforms include (1) removing food staple crops from strict notification lists that mandate extensive testing *additional to* the testing conducted by the breeding organization; (2) allowing the final multilocation testing stages of the breeding organization’s pipeline to serve as the trials on which release decisions are based, avoiding unnecessary duplication of tests by multiple organizations; and (3) introducing voluntary or automatic registration procedures that require submission of a minimum dataset characterizing the agronomic performance and other relevant characteristics of the variety. Deregistration of varieties is likely a weakly second-best option given the costs of implementation and the wider social and economic costs.

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<sup>11</sup> In the late 1980s, the decisions to ban rust-susceptible varieties were made following the annual “traveling wheat seminar” that included extensive farm and trial visits by wheat scientists and wheat program administrators. But while rust susceptibility was the foremost concern emerging from those visits, it was also determined that a ban would be imposed on any variety of Indian origin—suggesting a strong political motivation to the decision that may have had nothing to do with pathogen or productivity concerns.

## **Improving quality assurance systems**

Irrespective of varietal registration and release procedures, issues related to the regulation of seed quality are much more proximate to the concerns shared by industry and farmers. The market failures discussed earlier are most evident in the actual exchange of seed between seed providers and farmers—the point at which farmers buy seed and are often unable to assess *ex ante* the identity or quality of seed based solely on visual inspection, and where the seed provider may possess such information. This allows for the possibility of an inefficient market exchange with potentially welfare-reducing outcomes for the farmer. Thus, seed quality assurance systems have emerged in most countries to specifically address the inefficiencies created by asymmetries of information in seed markets. In the context of varietal turnover, quality assurance systems that provide farmers with a credible signal of genetic and physical quality can increase the willingness to switch from one improved variety to another.

Policy and regulatory reforms to improve seed quality systems can be viewed in terms of quality control systems that are internal to the seed provider and quality assurance systems that are external to the seed provider (Gildemacher et al. 2017). Internal quality control systems require investment in seed providers' capacity to manage seed production in a systematic manner. These systems fall outside the direct purview of public policy and regulation, and they are more of a topic for discussion of investments in technical capacity required to develop a robust seed industry. External quality assurance systems, on the other hand, are a matter of public interest, particularly where farmers rely on regulation because quality signals garnered from the market, from peers, or from other sources do not correlate well with actual seed quality.

As a case in point, consider seed certification as the highest standard of quality assurance. Seed certification is a common method of signaling to farmers that their seed—particularly for major field crops—is of a high and consistent quality in terms of genetic purity, physical purity, germination rate, and moisture content. Certification is typically provided based on point-by-point inspections designed to monitor and document seed production from field to bag. But there is also evidence—some anecdotal, some documented—to suggest that seed certification systems in many countries allow significant

quantities of off-type materials into the market, which may not be any better than farmer-saved seed (Deu et al. 2014; Biemond et al. 2013; Bishaw, Struik, and van Gastel 2012; Bongor, Ayele, and Kumsa 2004). Other studies suggest that certified seed itself does not provide farmers with the kind of quality signal it is intended to provide, causing them to rely on other seed sources to obtain better-quality seed, improved genetics, or information on either (Diallo 2009; Rana 2014). Despite this, strengthening seed certification systems and increasing the rate at which farmers purchase certified seed seem to have emerged as key policy goals in certain developing countries (Spielman and Kennedy 2016).

Yet alternatives exist. Gildemacher et al. (2017) describe four alternatives to standard state-run certification systems: self-control systems, group control systems, quality-declared seed (QDS), and truthful labeling. The first two are forms of firm- and industry-level self-regulation and are susceptible to moral hazard, principal-agent problems, and other social and economic issues. QDS and truthful labeling, on the other hand, may offer more scope for seed markets in developing countries.

QDS refers to a quality assurance standard that is less rigorous than conventional seed certification but still based on external and independent assessment and verification. See FAO (2006) for QDS guidelines. Such systems exist in a range of countries. In Tanzania, QDS has been in place since 2000. Ethiopia places the distribution of QDS prominently in its seed sector development strategy. A similar consideration for QDS finds mention in India's National Food Security Mission, Nepal's Seed Vision, and strategies being developed in other countries where rapid seed system development is a topic of policy discourse.

Importantly, QDS systems can be less costly than conventional certification systems. Gildemacher et al. (2017) estimate that the real costs of QDS amaranth seed in Tanzania amount to just 44 percent of certified seed. Where farmers' willingness to pay for quality seed is limited, lower-cost QDS seed may bring prices more in line with farmers' expectations.

Rather than fixate on certified seed distribution, many developing countries might do well to invest in these alternative quality assurance mechanisms. This could include the introduction of QDS systems that provide a lower standard of quality at a lower cost that is more commensurate with farmers'

existing expectations. Or it could include more incremental changes in procedures, such as allowing tests to be conducted by accredited private seed-testing laboratories rather than public seed quality assurance agencies or simply providing greater or more transparent information on procedures, testing criteria, fees, and testing timelines (Table 3.2). It may also involve the introduction of traceability systems for seed to help determine where quality issues occur between the production and distribution points in the supply chain. Point-of-sale monitoring for quality assurance also offers a lower-cost alternative to standard “field-to-bag” inspections. Similar cost savings could be achieved with digital solutions such as the e-verification system piloted in Uganda in which scratch-off labels are affixed to genuine agricultural inputs (seed and fertilizer packages) to provide farmers with a product code that can be validated via SMS to authenticate the product (FTF 2015; Ashour et al. 2015).

That said, there may be unintended consequences in any quality assurance system that seeks to formalize what is otherwise a functional informal seed system. Bringing small-scale seed producers under regulatory scrutiny—even with relatively lenient QDS standards—changes the cost structures of seed production. And if such changes reduce the returns to seed production by small-scale producers, then one might expect seed supply to decrease as producers exit the market.<sup>12</sup> The scale of this impact depends on the length and breadth of the adjustment period in which informal seed systems become more integrated into formal systems.

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<sup>12</sup> We thank Margaret McEwan and colleagues from the CGIAR Research Program on Roots, Tubers, and Bananas program for raising this issue in the context of vegetatively propagated crops.

**Table 3.2 Selected indicators on seed quality assurance procedures from the World Bank/IFC  
Enabling the Business of Agriculture 2016**

Indicator	Ethiopia	Kenya	Tanzania	Zambia	Bangladesh	Nepal	Ghana
Can the private sector be accredited to carry out the certification process?	No	Yes	Yes	Yes	n.a.	n.a.	Yes
Is there an official fee schedule for seed certification activities carried out by the public sector?	No	No	Yes	Yes	n.a.	n.a.	No

Source: World Bank Group (2016).

Note: n.a. = not applicable.

Despite these unintended consequences, such countries might still consider formal regulation of the seed system as a long-term goal. As such, many are likely to consider the introduction of truth-in-labeling laws as an end point in that process. Truth-in-labeling laws require seed providers to label key attributes of their seed products (for example, moisture content, purity level, and germination rate) and accept liability for products that do not contain such attributes. However, truthful labeling systems require investment in the judicial infrastructure necessary to provide effective recourse against those seed companies that fail to comply. Most countries have ample experience with lower quality assurance standards in the market for vegetable seed and other horticulture crops where quality is assured by truthful labeling, whether by local or multinational companies selling branded products or by virtue of the packaging on imported seed. But few have experience with judicial recourse specific to the complex issues related to seed quality.

Necessarily, no system is perfect. It is possible that inspection-intensive systems can produce certified seed that is of a lower genetic or physical quality than farmer-saved seed. It is also possible for truth-in-labeling regulations to provide insufficient inducements for companies to produce quality seed, especially if judicial infrastructure is weak. But given that seed certification systems may have outlived their usefulness, more practical quality standards may need to be considered if only to improve farmers' confidence in the ability of the market to provide new genetics embodied in seed. Whether this

accelerates varietal turnover is, however, an empirical question given the indirect nature of the impact pathway relative to, say, other mechanisms discussed in this paper.

Ultimately, several pragmatic approaches to improving quality assurance systems emerge. First, a sensible quality assurance system is likely to be crop-specific and appropriate to the quality expectations of farmers who cultivate that crop. Second, there is scope for decentralizing quality assurance systems and functions to a subnational level that, depending on the crop, is related to the geographic proximity between seed producers and farmers. Third, there is a role for independent quality inspection services, including private testing laboratories, certified inspectors, and other services that be subcontracted by public regulatory agencies.

### **Increasing access to early-generation seed and improved genetics**

Another commonly discussed means of accelerating varietal turnover is the introduction of new or more effective mechanisms to distribute publicly improved germplasm to private companies. This includes both breeder/prebasic and foundation/basic seed (collectively referred to as early-generation seed [EGS]) that crop breeders and seed multipliers use to produce finished products for farmers (BMGF/USAID 2015; Heemskerk et al. 2017b). We explore here several mechanisms designed to increase access to EGS: (1) increasing private companies' nonexclusive access to EGS; (2) increasing private companies' access to EGS on an exclusive basis; and (3) strengthening intellectual property rights regimes more generally. There is considerable variation among developing countries in the public policies and regulations governing genetic resources and intellectual property rights. This is illustrated in Table 3.3 with indicators extracted for selected countries with mature or transitional seed systems from the World Bank Group's (2016) *Enabling the Business of Agriculture* report.

**Table 3.3 Selected indicators on genetic resources policy and intellectual property rights from the World Bank/IFC *Enabling the Business of Agriculture 2016***

Indicator	Ethiopia	Kenya	Tanzania	Zambia	Bangladesh	Nepal	Ghana
Does the country currently have an implemented regulation governing plant breeders' rights?	Yes	Yes	Yes	Yes	No	No	No
Are private enterprises eligible to produce breeder/prebasic seed of local public varieties for use in the domestic market?	Yes	Yes	Yes	Yes	No	Yes	No
Are private enterprises eligible to produce foundation/basic seed of local public varieties for use in the domestic market?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Can the private sector access germplasm from your national genebank?	No	Yes	Yes	Yes	Yes	Yes	No
Is there an established system for licensing public varieties to private seed enterprises for production and sale in the domestic market?	No	Yes	Yes	Yes	Yes	No	No
Are private companies allowed to import materials for research and development of new varieties without further government field testing (that is, germplasm or seed varieties not listed in the national catalog of the importing country)?	No	Yes	No	No	Yes	No	Yes

Source: World Bank Group (2016).

As a starting point, consider India as the archetype of EGS management. The country's extensive reliance on self-pollinating crops (rice, wheat, and pulses) has led to the development of a largely nonmarket EGS allocation system involving public research programs, state agricultural universities, state-owned seed enterprises, private seed companies, and farmer cooperatives (see, for example, Pal and Tripp 2002). Each season, seed producers submit requests ("indents") for EGS to their respective state agricultural universities or research centers along with prepayment for the material. The Indian Council of Agricultural Research's All-India Coordinated Research Projects compile these indents and analyze them against demand forecasts before allocating EGS to the seed producers through the Ministry of Agriculture.

Though much larger in scale than similar systems in other countries, India's system is particularly effective in producing seed for self-pollinating crops that populate the high-volume, low-margin end of the seed market. It is also a system that allows the participation of many small domestic seed companies as well as several of India's large industrial conglomerates, both of which are keenly reliant on public breeding programs and the public supply of EGS. And while these companies may not have exclusive rights to the varieties they access from these public breeding programs, they nonetheless compete on nonprice attributes such as timeliness of delivery, quality of seed, packaging quality, sales of fertilizers and crop protection chemicals, geographic segmentation, and after-sales support.

Unfortunately, there are few successful replications of the Indian system in other countries and for other crops—at least in terms of the breadth and depth of participation from private companies and farmer cooperatives. For example, Bangladesh's 1993 National Seed Policy aimed to relegate the Bangladesh Agricultural Development Corporation (a state-owned enterprise) to the role of foundation seed producer for non-notified crops, thereby creating a financially viable public supplier of high-quality material to small- and medium-sized seed enterprises that could produce and market improved varieties directly to farmers (Naher and Spielman 2015). Similar designs were formulated for the Ethiopian Seed Enterprise, also a state-owned enterprise, but they have yet to be realized. Other countries such as Tanzania have long-standing policies that impede the provision of EGS to private seed providers.

Yet a strong argument can be made for a transition from public-sector-led seed retailing to public provision of EGS for multiplication and retailing by private companies and farmer cooperatives (Heemskerk et al. 2017b). Public breeding programs can use an EGS handoff system to retain their focus on breeding rather than seed multiplication for retail purposes, a function observed in many developing countries. They can also use EGS sales as a means of financing research activities.

In some contexts, however, nonexclusive access to public varieties may not be incentive enough for private actors to invest in seed production and distribution in a manner that accelerates varietal turnover. In theory, intellectual property rights (IPRs)—plant patents and plant variety protections—encourage private investment in the development of new varieties by providing the IPR owner with a temporary monopoly that allows it to appropriate the gains from innovation and recoup the R&D costs associated with variety development. So long as society is willing to allow for the efficiency losses and private gains associated with a temporary monopoly as compensation for innovation, then IPRs can be a powerful tool in fostering technical change.

Empirical evidence of IPRs' contribution to agricultural productivity growth is mixed, and in developing-country agriculture the evidence is largely ambiguous (Naseem, Spielman, and Omamo 2010) or specific to the crop and the technology embodied in the seed (Spielman and Ma 2016).<sup>13</sup> Ultimately, it may be the case that IPRs do not matter to developing-country agriculture because companies with significant intellectual property portfolios—typically, multinational crop-science firms—are unlikely to seek IPR protection for their technologies in most developing countries, thus giving developing-country researchers and farmers unimpeded freedom to operate (Binenbaum et al. 2003).<sup>14</sup>

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<sup>13</sup> Several studies suggest that the United States' Plant Variety Protection Act of 1970 boosted cotton and wheat yield growth rates (Kolady and Lesser 2009; Naseem, Oehmke, and Schimmelpfennig 2005; Perrin, Kunnings, and Ihnen 1983), although confounding evidence was found for wheat and tobacco yields (Alston and Venner 2000; Babcock and Foster 1991). Similarly positive evidence for canola and wheat yields from Canada's Plant Breeders' Rights Act of 1990 also exists (Carew and Devadoss 2005; Carew, Smith, and Grant 2009).

<sup>14</sup> That said, there are also concerns that strong IPR regimes such as those based on the 1991 standards established by the International Union for the Protection of New Varieties of Plants would have strong negative impacts on farmers' ability to save, exchange, and sell seed in informal networks and markets that also constitute a means of accelerating varietal turnover (De Jonge and Munyi 2017).

Nonetheless, some thought has been given to the possibility of extending exclusive rights—via agreement terms and conditions on restricted use, limited exclusivity, registration rights, or fee-based access—over newly released public varieties to private seed companies as a means of promoting their distribution, popularization, and adoption (Heemskerk et al. 2017a). Assuming profit-maximizing seed companies have a stronger incentive to distribute and market new varieties than their state-owned counterparts, it may make sense to grant these companies exclusive rights or licenses for new varieties released from public breeding programs. Such rights or licenses could be expansive across both geography and duration, or more limited. They could be priced up-front (for example, on a per line basis), priced on a royalty-based formula, or priced through auctions, sealed bids, or other processes. Innovations along these lines have been explored in the international agricultural research system, for example, in the hybrid parent line consortia for sorghum, pearl millet, and pigeonpea at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and for maize at CIMMYT. However, they also open the door to questions about whether exclusive rights (whether de facto or de jure) cut against a public institute’s fundamental public goods provision mandate, and whether private firms may use exclusive rights to suppress the release of new varieties and defend their market position. Moreover, the ability of a company to profit from an exclusive rights arrangement is likely dependent on the size of the market in terms of seed volumes (and, relatedly, seed replacement rates) and value.

Taken together, these mechanisms—increasing nonexclusive or exclusive access to EGS, and strengthening IPR regimes more generally—can incentivize the distribution and marketing of new varieties by private actors. To date, however, insufficient evidence exists to suggest where, or under what conditions, these arrangements might work to accelerate varietal turnover. Further experimentation along these lines is desirable, as is closer analysis of the revenue-generating potential of these arrangements for public breeding programs, the role for standard and transparent licensing agreements, the viability of end-point royalty systems, and other mechanisms (see, for example, Heemskerk et al. 2017a; GRDC 2011).

## **Leveraging input subsidy programs**

Public subsidies and transfers are often viewed as an attractive way of encouraging both varietal adoption and turnover particularly where farmers may be liquidity- or credit-constrained, risk averse, or otherwise constrained in their decision space. Subsidies may take several forms, including the free provision of small starter kits and handouts of sample packets at seed fairs; retail discounts on large seed consignment purchases; implicit subsidies on credit, transport, warehousing, and seed production costs incurred by seed providers; the inclusion (and exclusion) of specific varieties in (from) an input subsidy program; or tying the introduction of a new variety to benefits distributed in a social protection program. Subsidies on improved varieties are often built into larger input subsidy programs that aim to increase the availability and affordability of costly fertilizers, with seed being a relatively incidental part of the overall package in terms of cost and volume, though not in terms of the expected impacts on productivity.

Such programs may be administered as universal subsidies across given geographical or administrative units. For example, universal programs were pursued by newly independent African nations that emulated policies they observed in Asia during the Green Revolution, although many of these African policies were gradually dismantled during the structural adjustment programs of the late 1980s due to their considerable fiscal burden. In the early 2000s, fearing the high costs of food imports in the face of stagnating yields, a number of African nations reinstated so-called “smart” subsidies.<sup>15</sup> A common vehicle for implementing these programs has been input vouchers, typically targeted to specific beneficiaries using tools such as means testing, targeted voucher distributions, community-based identification, self-selection, market segmentation, or combinations thereof. However, an extensive literature demonstrates with increasingly rigorous methods that “smart” input subsidies are not as smart as had been hoped. For instance, they tend to crowd out the commercial seed and fertilizer industries, are often captured by local farming elites, and serve as means of incumbent politicians to garner constituents’

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<sup>15</sup> Among other criteria, input subsidies are considered to be “smart” if (1) crop productivity and food security benefits outweigh what might have been achieved through alternative investments; (2) they stimulate investment in input distribution by private suppliers and agro-dealers; and (3) they are accompanied by a clear exit strategy (Morris et al. 2007).

support. On the other hand, much of the evidence also confirms strong positive effects on crop yields, farmer income, and poverty rates.<sup>16</sup>

Chirwa and Dorward (2013), Mason and Ricker-Gilbert (2013), and Mason and Smale (2013) found evidence of crowding out in the seed industries of Zambia and Malawi, while Mason and Smale (2013) found positive impacts of subsidized seed use on indicators of household well-being. Chirwa and Dorward (2013) reported that 84 percent of Malawian farmers who benefited from the input supply program stated that they obtained “the hybrid variety they wanted,” but they did not name hybrids. While rigorous estimation of causal impacts still poses a challenge for many studies in this vein, there is a clear indication that input subsidy programs, seed market development, and varietal turnover are inextricably linked.

For the purposes of this paper, the key issue is how these programs affect the change from one improved variety to another. Despite a burgeoning literature on the impacts of fertilizer subsidies in Africa and Asia, there is little research on the impacts of seed subsidies on varietal turnover. We know of no published analysis about (1) whether and how specific seed varieties are selected for inclusion in a given subsidy program, or (2) how input subsidies influence variety choice—let alone whether the subsidies had an impact on the turnover of specific varieties.

That said, several recent studies from Malawi and Zambia shed some light on these questions. With respect to the inclusion of specific varieties in Zambia’s input subsidy program, concerns have been expressed about the appropriateness of recommended inputs including varieties. Although the district agricultural coordinators report which varieties their district would like to receive to the Coordination Office at the Ministry of Agricultural Headquarters, not all requests are necessarily obliged. Anecdotally, farmers surveyed in areas with short growing seasons reported receiving late-maturing varieties (Nicole

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<sup>16</sup> In many countries that are host to advanced or transitional seed systems, subsidies on seed and fertilizer remain a fairly common tool used to increase food staple production, and they represent a substantial share of public spending on agriculture (Shively and Ricker-Gilbert 2013). According to Jayne and Rashid (2013), in Africa south of the Sahara as of 2011, 10 African countries spent 28.6 percent of their public expenditures (US\$1.05 billion) on input subsidy programs (universal subsidy programs in Mali, Burkina Faso, Ghana, Senegal, and Nigeria; more targeted programs in Kenya, Malawi, Tanzania, Zambia, and Ethiopia). Note that Jayne and Rashid (2013) classify Ethiopia’s input subsidy program as neither universal nor targeted given the unique nature of its design.

Mason, personal communication, June 28, 2016). With respect to the impact of Malawi's input subsidies on varietal turnover, Holden and Fisher (2015) report that Malawi's program played a significant role in accelerating the adoption of drought-tolerant (DT) maize varieties—presumably replacing hybrids or improved varieties already being cultivated by farmers—between inception in 2005/2006 and 2011/2012; however, farmers they interviewed stated that commercial supplies remained inadequate to meet demand.<sup>17,18</sup>

At face value, the input subsidy program in Zambia (and maize cultivation patterns more generally) does not seem to induce the concentration of area in fewer varieties, but no analysis has been conducted to test this hypothesis explicitly. Baseline research conducted by HarvestPlus and CIMMYT showed that no single maize variety dominated in the major maize-producing zones of the country, and no individual variety accounted for more than 10 percent of total area under maize cultivation (De Groote et al. 2014). As a result, Zambia's maize seed industry is competitive and no single variety occupies more than a minor percentage of maize area, although in reality, the major client of the maize seed industry is the Zambian government (Kassie et al. 2013).

In fact, the maize seed industry is relatively competitive in eastern and southern Africa. This is indicated by the presence of several large companies and an even larger number of smaller companies, though their major clients are typically national governments via input support programs (Langyintuo et al. 2010; Kassie et al. 2013). Further, companies readily state that the input subsidy program now offers them a guaranteed market that includes poorer smallholder farmers, who are not reliable clients. This does not, however, fully address the question of whether competition in the maize seed market is causally linked to accelerated varietal turnover, suggesting the need for further research.

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<sup>17</sup> Compared with Ethiopia, Zambia, Zimbabwe, Uganda, and Tanzania, Malawi had the highest share of maize plots planted to DT maize.

<sup>18</sup> In the Philippines, David (2006) makes a strong case for scaling down a program to promote hybrid rice partly because the hybrids (totaling between just one and six hybrids during the first years of the program) promoted under the program were poorly adapted to the targeted agroecologies and needs of the farmers, thereby distorting farmers' decision making about appropriate variety and input choices.

A possible starting point to test this relationship is the flexible e-voucher system piloted in Zambia during 2015/2016 in 13 districts (which initially appears to function alongside the input support program). The program is intended to save government resources by shifting the burden of transactions to agro-dealers while enabling farmers to purchase the input of their choice directly. This same e-voucher system could provide an opportunity to observe whether, if supplied by local agro-dealers with a range of varieties, including newer releases, farmers choose to purchase a more diverse portfolio compared with the previous subsidy program—and observe how this portfolio changes over a period of years.

With respect to choice, one informed observer reported that farmers primarily used the flexible voucher system to obtain fertilizer rather than seed because it is the costlier input (Eliab Simpungwe, International Center for Tropical Agriculture, personal communication, August 20, 2016). Kuteya et al. (2016) report that 61 percent of farming households redeemed vouchers for fertilizer and 24 percent used them for maize seed, while the remaining 15 percent obtained a diverse range of other inputs. They perceive the e-voucher as having great potential to diversify farming relative to the input subsidy program, also recommending a number of improvements in its implementation. Considering specific varieties, the input support program and the flexible system are both being used to introduce vitamin A–fortified (“orange”) maize. If implemented simultaneously, these two programs provide a natural experiment for testing effects of subsidy form on variety choice and variety turnover.

Ethiopia’s seed system may offer similar opportunities for experimentation. With its implicit subsidies on the distribution of seed through a government-supervised network of rural administrative offices, credit providers, and cooperatives, Ethiopia’s system exemplifies a highly controlled form of a state-managed seed system (Louwaars, de Boef, and Edeme 2013; Spielman et al. 2010). In a system of this type, influencing or accelerating varietal turnover may be relatively easy to achieve at scale. Moreover, such efforts may allow for the testing of alternative levels of private-sector engagement ranging from the subordinate role that companies currently play to the state as outgrowers and suppliers to the public supply system, to the possibility of direct seed marketing to farmers by those same companies (see Benson, Spielman, and Kasa 2014). However, the hidden costs of Ethiopia’s subsidized system are

not well understood, although trying to increase efficiency in the distribution of new varieties of wheat, teff, and maize (along with fertilizer, credit, and agronomic advice) has been central to efforts of the Agricultural Transformation Agency (ATA) and the Ministry of Agriculture and Natural Resource Management (MoANRM) for the past five years.

An alternative way of using subsidy programs to accelerate varietal turnover is by targeting subsidies on a variety-specific basis, with the goal of removing older varieties from production once they have been succeeded by newer varieties with higher yields or other competing traits. Although this could also be achieved through deregistration of varieties (discussed earlier) or banning their production, sale, or cultivation, the inclusion (or exclusion) of specific varieties in an input subsidy program may offer a less draconian approach to encouraging varietal turnover. The advantage of variety-specific subsidies is that they can reduce the cultivation of varieties that are susceptible to identified pest and disease pressures, and they create the conditions for rapid replacement with less susceptible varieties.

However, the challenges associated with such measures are nontrivial. A variety-specific subsidy strategy requires careful calculation of the economic costs, benefits, and trade-offs associated with the threat posed by continued cultivation of an older variety and its replacement with a new variety. It is exceptionally difficult to identify threshold values at which susceptibility of a specific variety becomes economically or socially unacceptable, particularly when the probability of an adverse event over a large area is low and the incidence and losses associated with that event are not uniformly distributed across farm types or geographies. A variety-specific subsidy strategy also requires careful accounting for factors such as consumer preferences for older varieties with production, processing, cooking, or taste qualities or other attributes that are particular to a specific market niche; the costs of implementing a variety-subsidy or variety-replacement scheme across geographically dispersed smallholder farms and highly fragmented seed markets; and the possibility that seed companies and farmers themselves may choose to keep older varieties in circulation if demand exists.

Still another way of using subsidy programs to accelerate varietal turnover is through advance purchase commitments or large-scale public procurement of a specific variety or varieties for distribution

to farmers through input subsidy programs, social protection programs, or other public investments. Such approaches have been discussed in the contexts of seed enterprise financing, emergency seed relief, and incentivizing breeders (Minneboo et al. 2017; Naseem, Spielman, and Omamo 2010). But the risks, trade-offs, and unintended consequences associated with these approaches are similar to many of those described earlier, and in the absence of credible evaluations, their impact on varietal turnover remains unknown.

In summary, the impact of input subsidies on varietal turnover is still unknown. Evidence about their direct impact on variety choice, varietal turnover, and the spatial and temporal diversification of varieties is virtually nonexistent. However, innovative mechanisms that direct public resources through a range of subsidy and transfer mechanisms—input subsidy programs, social protection programs, advance purchase commitments, or public procurement programs—offer new opportunities to investigate their impact on varietal turnover.

### **Strengthening seed enterprises' marketing capabilities**

Next, we turn our attention to the role of state-owned seed enterprises, farmers organizations, cooperatives, and other quasi-commercial entities.<sup>19</sup> These are typically entities with a public service mandate, established and sustained in recognition that certain crops will continually require public intervention because the private returns to developing and marketing seeds and traits will never exceed the social returns. To what extent would investments aimed at improving their marketing capabilities lead to acceleration in varietal turnover among the farmers they target?

There is a strong case for investing more in these types of entities where crop-specific market failures are persistent. Public investments that improve their capabilities in assessing client demand, marketing their products, and building profitable, commercially oriented retail networks may be the most cost-effective way of accelerating varietal turnover where market failures are persistent and commercial

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<sup>19</sup> Efforts to strengthening marketing capacity in more commercially oriented small- and medium-scale seed enterprises is also a topic for further exploration. For example, this has been the focus of efforts such as the Program for Africa's Seed. Systems under the Alliance of a Green Revolution in Africa. An assessment of such initiatives is, however, beyond the scope of this paper.

incentives are weak. While investments along these lines can crowd out private investment in hybrid maize seed markets and other markets where private firms have a clear path toward profitability, these investments have been historically central to the promotion of improved varieties for wheat, rice, and other self-pollinated crops in both industrialized and developing countries.

Farmers' organizations are often similar in terms of mandate, balancing public service with private, profit-making incentives. That said, few state-owned seed companies or farmer organizations invest significantly in demand assessment and product marketing. Meanwhile, tools for analyzing market conditions and farmer preferences—for example, participatory plant breeding and varietal selection programs—are not designed to operate at a scale that can sufficiently inform marketing strategies to accelerate varietal turnover. And even with such investments, demand assessment and market analysis are challenging in seed markets where demand for the final product derives from demand for the final commodity, where markets for both may exist under less than perfectly competitive conditions, where both production and marketing are fraught with risk and uncertainty, and where high-resolution, variety-specific data may not be readily available.

A novel effort to improve marketing capabilities in state-owned seed enterprises is illustrated by the Ethiopian ATA and MoANRM. Together with other actors in Ethiopia's seed system, these organizations have worked with the Ethiopian Seed Enterprise (ESE), the regional seed enterprises, and regional extension services to popularize new varieties with improved data management, market analysis tools, information and communications technologies, and other novel ideas (see Benson, Spielman, and Kasa 2014; Spielman and Mekonnen 2012; Dalberg 2012). Given that ESE and the regional enterprises are key sources of improved seed supply throughout Ethiopia, and that extension services are the key sources of information about these varieties, it is expected that these investments in capacity will improve the accuracy of demand assessment dramatically, thereby leading to an increase in the adoption of modern varieties and an acceleration of varietal turnover for crops such as wheat and teff, as well as maize. Although evidence is emerging of rapid varietal turnover for teff in the last five years in several districts

(Minten, Taffesse, and Brown, forthcoming), further analysis is needed to causally link this turnover to actions taken by state-owned seed enterprises, extension services, and other actors in the seed system.

Realistically, however, it is difficult to imagine a state-owned seed company, farmer organization, or cooperative running a savvy marketing operation or retail network, or an extension system transforming itself into a cutting-edge sales force. Even market leaders with extensive distribution networks like KSC and the Bangladesh Agricultural Development Corporation rely on product portfolios based on varieties that were released more than 20 years ago and require little marketing (for example, H614 hybrid maize in Kenya and BR28 and BR29 rice in Bangladesh). There is probably little incentive for these companies to introduce new varieties because of the fixed costs associated with marketing them to farmers and the conflicting goals of ensuring national food security and maximizing profit (or, at the very least, minimizing losses).

Thus, the prospects for companies becoming a means to accelerate varietal turnover remain limited without changes in how public agency incentives are structured and how competition policy is applied in seed markets dominated by state-owned enterprises. There is some evidence to suggest that state-owned seed companies in China have carved out a niche in increasingly commercial and competitive markets where varietal turnover is relatively high for some crops (Hu et al. 2011). However, the replicability of China's experience in other countries may be limited given the unique attributes of its agricultural innovation and product markets.

This leaves us with unanswered questions. Can state-owned enterprises or extension services be transformed into more dynamic and responsive marketing operations? Can they adapt their products and services to the needs of a diverse clientele? Most importantly, do they have any control over the pricing of their products or services to generate the revenues needed not only to cover recurrent costs but also to meet the costs of marketing new varieties and accelerating varietal turnover in a sustained manner? State-owned seed enterprises and extension services are not likely to disappear or to be privatized anytime soon, so these questions warrant further consideration.

## **Leveraging competition policy and antitrust regulations**

A relatively unexplored policy approach to accelerating varietal turnover is the application of competition policy and the enforcement of antitrust regulations in the market for seeds and traits. Concerns related to market structure, competition and innovation are raised by Pray and Ramaswami (2001), Pray et al. (2001), and Ramaswami (2002) in the context of India's seed market.

It has been observed, for example, that markets for maize seed in parts of eastern and southern Africa are dominated by single firms that, as a result of their market power, tend to promote tried-and-true varieties and hybrids at the expense of newer ones. Thus, Langyintuo et al. (2010) argue that without the provision of credit to private investors in eastern and southern Africa, the region's seed markets will remain highly concentrated.

Sure enough, South Africa's courts demonstrated their concern with these issues in 2012 when reviewing a proposed merger between Pannar Seed and Pioneer Hi-Bred International. The merger's go-ahead was approved on appeal (following similar decisions made by competition authorities in other eastern and southern African countries). This approval may have occurred partly because the potential for innovation a Pannar–Pioneer merger could bring to farmers outweighed concerns about the consequences of economic rent extraction in a market controlled by just two firms. But it is unknown whether either outcome has been realized, suggesting the need for more empirical analysis of seed industry structure, conduct, and performance and the impact of changes in industry attributes on sustained varietal turnover. This may suggest that while there is scope to use competition policy and antitrust regulations to increase seed market competition, the impact on innovation—new seeds and traits—and varietal turnover may be indirect and inconclusive at best.

Related to this is the question of whether antitrust regulations can be used to induce companies to withdraw obsolete varieties and introduce new ones on the market. The answer depends partly on whether the country in question has the requisite antitrust regulations on the books and the capacity to enforce them, and partly on whether the predicted increase in competition resulting from reductions in a company's market power will lead to the introduction of new varieties and an acceleration in varietal

turnover. There are no studies explicitly focused on developing-country seed systems that explore the link between market concentration and varietal turnover.<sup>20</sup> Moreover, economic theory and evidence from other markets and countries often point to a complex, often inconclusive relationship between competition and innovation.

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<sup>20</sup> Studies of seed industry structure, conduct, and performance conducted in the United States include Fuglie et al. (2011), Brennan et al. (2005), and Fernandez-Cornejo (2004), among others, particularly in response to the growth of agricultural biotechnology in the 1990s. The topic has been explored much less in Asia and Africa, with the exceptions of Spielman et al. (2014) and Langyintuo et al. (2010). None, however, explicitly analyze the relationship between industry attributes and varietal turnover.

## 4 A SEQUENCING OF POLICY REFORMS

It is difficult to formulate an overarching policy reform agenda—a generalizable blueprint—to accelerate varietal turnover. Solutions are specific to the crop, country, and market in question and are likely to change over time as opportunities and threats to the seed system evolve. That said, there are several short-, medium-, and long-term policy reforms that are worth exploring across many countries where low rates of varietal turnover are a concern to policymakers, researchers, and farmers.

In the short term, there is scope for introducing policy reforms that focus on regulatory changes and strategic investments that strengthen seed providers' ability to market and distribute new varieties to farmers. These include withdrawing costly, time-consuming, or otherwise onerous varietal registration and release procedures; curating and warehousing varietal registration information on a broadly accessible platform; and designing and implementing regional harmonization agreements for varietal registration or mutual recognition of registered varieties. The social and economic benefits of these legal, regulatory, and administrative changes are likely to far outweigh their costs.

A next step in the short term is to explore alternative quality assurance systems, possibly reducing the reliance on field-to-bag inspection systems for certified seed in favor of quality-declared and truthfully labeled seed. That said, such systems must be accompanied by commensurate investments in the capacity of seed quality assurance agencies to monitor seed market activities across the supply chain, and the capacity of judicial and administrative bodies to review allegations of, and enforce penalties on, seed providers who distribute substandard seed. The pursuit of both reforms in tandem is a complex undertaking. And while it may lead to the more rapid release of new varieties, it does not necessarily guarantee an acceleration in varietal turnover.

Another short-term reform requiring a more innovative or experimental approach is the inclusion (or exclusion) of specific varieties in input subsidy programs. This approach provides policymakers with a potentially direct and immediate lever to affect varietal turnover, although the fiscal costs, economic trade-offs, and unintended consequences of such programs are nontrivial considerations. For this reason,

this option should be accompanied by rigorous evaluation not only of a program's impact on varietal turnover rates but also of overall productivity, welfare, and cost-effectiveness.

In the medium term, there is scope to transform the role of public breeding programs, national research systems, and state-owned seed enterprises into suppliers of EGS for use in retail seed production by private seed providers including domestic seed companies, farmer associations, cooperatives, and other organizations. This approach requires substantial investment in building the production capacity and business acumen of smaller-scale seed producers in what are often fragmented and highly dispersed markets for a broad range of crops. Again, the success of this approach in accelerating varietal turnover hinges on the emergence of a well-integrated, vibrant, and competitive seed system.

Alternatively, there is some scope to transform state-owned seed enterprises into more competitive market agents themselves by investing in their capacity to assess demand, market their products, and expand their distribution networks. This option is, however, an unlikely route to accelerating varietal turnover without sufficient changes in public-agency incentives and competition policy in the seed market, and it may lead to crowding out of other seed providers.

In the long term, focus may best be placed on developing consensus around country- and crop-specific visions for how seed systems and markets should evolve to accelerate varietal turnover. In few developing countries does a strong consensus exist among seed system actors and stakeholders about how to accelerate varietal turnover. As a result, policies are continually formulated without complete recognition of their trade-offs and unintended consequences. There is likely no single set of rules or regulations that will lead a country directly to accelerated varietal turnover, and no single strategy that can satisfactorily address all crops at once. Nonetheless, this paper has tried to suggest possible policy and regulatory levers that could increase smallholders' access to the latest improved varieties—improved genetics—and accelerate the rate of varietal turnover in smallholders' fields. These levers are invariably specific to the crop, market, and country, and this report focuses primarily on major field crops in transitional or mature seed systems in developing countries.

Among all the countries discussed in this paper, several offer an opportunity for further experimentation with crop-specific policy reforms designed to accelerate varietal turnover. Zambia emerges as a leading candidate given the introduction of its flexible e-voucher system piloted in 2015/2016. Malawi's input subsidy program may similarly offer opportunities for policy innovation in the near future. In Asia, there is also scope to explore these issues in the context of policy and regulatory reforms that may be leading countries down more risk-prone paths, including protectionist policies that can militate against the introduction of new varieties—as in Nepal—or state-led policies that may be crowding out private investment—as in Bangladesh. Other countries offer similar opportunities to experiment around innovative financing arrangements such as advanced market commitments, introduction of quality-declared or truthfully labeled seed systems, or the investigation of antitrust issues in seed markets.

Importantly, a number of policy directions being pursued by several countries warrant closer reconsideration. A key example is the policy prioritization of increased seed replacement rates in India, which is being advanced without commensurate emphasis on accelerating varietal turnover. Only in the case of hybrid crops does this make immediate sense, and for most other crops the emphasis on *only* seed replacement is a misplaced policy priority. Similarly, policy discussions around variety-specific bans are unlikely to succeed given the experiences discussed earlier.

Finally, in exploring ways to accelerate varietal turnover, it is important to be continually reminded of two points. First, the success of a policy change, regulatory reform, or public investment depends not on its ability to encourage a one-time switch from one improved variety to another, but on its ability to encourage a continuous or repeated process of varietal turnover by farmers. Second, the improvement and release of new varieties is just one step along the pathway to varietal turnover and broader technical change and productivity growth in agriculture. Third, productivity- and welfare-improving outcomes depend on widespread changes in the behaviors and practices of individual farmers and farm households whose decisions are shaped by complex interaction between supply- and demand-related factors, individual circumstances, preferences, and expectations.

## 5 CONCLUDING REMARKS

A considerable body of analysis on varietal turnover emerged from concerns that farmers who had initially adopted higher-yielding varieties during the Green Revolution in South Asia were not replacing them with higher-yielding varieties embodied with newer sources of disease resistance. This concern has grown in other countries in South Asia and in Africa south of the Sahara that are host to relatively advanced or transitional seed systems and markets. Policymakers and researchers in these countries are (or should be) turning their attention not only to increasing adoption rates but also to accelerating varietal turnover. In a modern agricultural sector, varietal turnover protects and sustains yields over time, and it should thus be a policy goal and a closely monitored indicator of the potential for agricultural productivity growth.

As breeders and other agricultural scientists improve their breeding techniques and foresighting abilities, it is expected that a continuous stream of improved varieties will emerge to address the threats of biotic and abiotic stress associated with climate change, as well as changes in the economics of farming associated with demographic transitions, income growth, urbanization, and changing consumer diets and preferences. For some crops in some countries, this is already happening, but the absence of sufficient attention given to reforming policies, regulations, and investments that influence varietal turnover could constrain the impact of this stream of benefits.

Conversely, better breeding systems and foresighting abilities could allow for planning and priority setting that account for the inherent trade-offs between an optimal rate of varietal turnover from society's perspective as a whole and the rate that is economically optimal for an individual farmer or private seed company. Public policy is a key element in this planning process, particularly in advanced and transitional seed systems, and particularly where noncommercial staple crops are concerned. This suggests that opportunities exist to accelerate the rate of varietal turnover for many of these crops and countries through a range of carefully designed and well-sequenced policy and regulatory reforms.

Several points emerge from this paper. First, there is considerable scope in many countries to reduce the regulatory costs and burdens associated with varietal registration and release. Second, there is scope to reduce the regulatory costs and burdens associated with seed quality assurance, but only to the extent that such reforms are accompanied by parallel investments in the infrastructure needed to improve seed providers' credibility as purveyors of quality genetics that, in turn, may accelerate varietal turnover. Third, policies that extend either nonexclusive or exclusive access to public germplasm for private companies are a possible means of accelerating the distribution and marketing of new varieties, but they require further analysis to suggest the conditions under which these arrangements might accelerate varietal turnover. Finally, although inclusion of new varieties in input subsidy programs may help promote varietal turnover, these gains need to be carefully weighed against the opportunity costs of such programs and, in particular, the difficulties faced when withdrawing such subsidies.

Ultimately, this returns us to a well-articulated first-best option for promoting varietal change: strategic investment in an effective research system and policies that encourage the development of commercial seed markets. Investments and incentives that support the breeding and commercialization of new varieties are likely the most effective means of accelerating varietal turnover. Investments can take the form of increased public spending on the physical, scientific, and human capital required by public breeding programs, or on the structural, organizational, and management reforms required to improve their performance. Incentives can take the form of credit concessions, tax breaks, or research subsidies for companies developing and marketing successor varieties. Many of the policy options discussed in this paper complement these investments and incentives.

## REFERENCES

- Abate, T., M. Fisher, T. Abdoulaye, G. T. Kassie, R. Lunduka, P. Marenza, and W. Asnake. 2017. “Characteristics of Maize Cultivars in Africa: How Modern Are They and How Many Do Smallholder Farmers Grow?” *Agriculture and Food Security* 6 (30): 1–17.
- Ahmed, A. 2013. *Bangladesh Integrated Household Survey (BIHS) 2011–2012*. Dataset. Washington, DC: International Food Policy Research Institute.
- Almekinders, C. J. M., and N. P. Louwaars. 2002. “The Importance of the Farmers’ Seed Systems in a Functional National Seed Sector.” *Journal of New Seeds* 4: 15–33.
- Alston, J. M., C. Chan-Kang, M. C. Marra, P. G. Pardey, and T. J. Wyatt., 2000. *A Meta-analysis of Rates of Return to Agricultural R&D: Ex Pede Herculem?* Research Report 113. Washington, DC: International Food Policy Research Institute.
- Alston, J. M., G. W. Norton, and P. G. Pardey. 1995. *Science under Scarcity*. Ithaca, NY: Cornell University Press.
- Alston, J. M., P. G. Pardey, and V. H. Smith. 1999. *Paying for Agricultural Productivity*. Baltimore, MD: Johns Hopkins University Press.
- Alston, J. M., and R. J. Venner. 2000. *The Effects of the U.S. Plant Variety Protection Act on Wheat Genetic Improvement*. EPTD Discussion Paper 62. Washington, DC: International Food Policy Research Institute.
- Apple, J. L. 1977. “The Theory of Disease Management.” In *Plant Disease: An Advanced Treatise*, edited by J. G. Horsfall. New York: Academic Press.
- Ar-Rashid, H., M. Ali, and D. Gisselquist. 2012. *Private-Sector Agricultural Research and Innovation in Bangladesh: Overview, Impact, and Policy Options*. Agricultural Science and Technology Indicators Initiative Project Paper. Washington, DC: International Food Policy Research Institute.
- Ashour, M., L. Billings, D. O. Gilligan, and N. Karachiwalla. 2015. *An Evaluation of the Impact of E-Verification on Counterfeit Agricultural Inputs and Technology Adoption in Uganda: Baseline Report*. Washington, DC: International Food Policy Research Institute. Accessed October 2016. <http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129247>.
- Babcock, B. A., and W. E. Foster. 1991. “Measuring the Potential Contribution of Plant Breeding to Crop Yields: Flue-Cured Tobacco, 1954–87.” *American Journal of Agricultural Economics* 73 (3): 850–859.
- Benson, T., D. J. Spielman, and L. Kasa. 2014. *Direct Seed Marketing Program in Ethiopia in 2013: An Operational Evaluation to Guide Seed-Sector Reform*. Washington, DC: International Food Policy Research Institute.
- Biamond, P. C., O. Oguntade, T.-J. Stomph, P. L. Kumar, A. Termorshuizen, and P. Struik. 2013. “Health of Farmer-Saved Maize Seed in North-East Nigeria.” *European Journal of Plant Pathology* 137 (3): 563–572.
- Binenbaum, E., C. Nottenburg, P. G. Pardey, B. D. Wright, and P. Zambrano. 2003. “South–North Trade, Intellectual Property Jurisdictions, and Freedom to Operate in Agricultural Research on Staple Crops.” *Economic Development and Cultural Change* 51 (2): 309–335.
- Binswanger, H. P., and J. von Braun. 1991. “Technological Change and Commercialization in Agriculture: The Effect on the Poor.” *World Bank Research Observer* 6 (1): 57–80.
- Bishaw, Z., and A. J. G. van Gastel. 2009. “Variety Release and Policy Options.” In *Plant Breeding and Farmer Participation*, edited by S. Ceccarelli, P. E. Guimaraes, and E. Weltzien, 565–587. Rome: Food and Agriculture Organization of the United Nations.
- Bishaw, Z., P. C. Struik, and A. J. G. van Gastel. 2012. “Farmers’ Seed Sources and Seed Quality: 1. Physical and Physiological Quality.” *Journal of Crop Improvement* 26 (5): 655–692.
- BMGF/USAID (Bill and Melinda Gates Foundation/United States Agency for International Development). 2015. *Early Generation Seed Study*. Seattle, WA: BMGF; Washington, DC: USAID. Accessed May 2017. <https://agriknowledge.org/downloads/dv13zt22g>.

- Bonger, T., G. Ayele, and T. Kumsa. 2004. *Agricultural Extension, Adoption, and Diffusion in Ethiopia*. Ethiopian Development Research Institute (EDRI) Research Report 1. Addis Ababa: EDRI.
- Bonny, S. 2014. "Taking Stock of the Genetically Modified Seed Sector Worldwide: Market, Stakeholders, and Prices." *Food Security* 6 (4): 525–540.
- Brennan, J. P. 1984. "Measuring the Contribution of New Varieties to Increasing Wheat Yields." *Review of Marketing and Agricultural Economics* 52: 175–195.
- Brennan, J. P., and D. Byerlee. 1991. "The Rate of Crop Varietal Replacement on Farms: Measures and Empirical Results for Wheat." *Plant Varieties and Seeds* 4: 99–106.
- Brennan, M., C. Pray, A. Naseem, and J. F. Oehmke. 2005. "An Innovation Market Approach to Analyzing Impacts of Mergers and Acquisitions in the Plant Biotechnology Industry." *AgBioForum* 8 (2/3): 89–99.
- Byerlee, D., and C. Eicher, eds. 1997. *Africa's Emerging Maize Revolution*. Boulder, CO: Lynne Rienner.
- Carew, R., and S. Devadoss. 2005. "Quantifying the Contribution of Plant Breeders' Rights and Transgenic Varieties to Canola Yields: Evidence from Manitoba." *Canadian Journal of Agricultural Economics* 51 (3): 371–395.
- Carew, R., E. G. Smith, and C. Grant. 2009. "Factors Influencing Wheat Yield and Variability: Evidence from Manitoba, Canada." *Journal of Agricultural and Applied Economics* 41: 625–639.
- Charyulu, D. K., M. C. S. Bantilan, A. R. Laxmi, and D. S. Moses. 2015. "Analysing Scientific Strength and Varietal Generation, Adoption, and Turnover in Peninsular India: The Case of Sorghum, Pearl Millet, Chickpea, Pigeonpea, and Groundnut." In *Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*, edited by T. S. Walker and J. Alwang. Wallingford, UK: CABI.
- Chirwa, E., and A. Dorward. 2013. *Agricultural Input Subsidies: Recent Malawi Experience*. Oxford, UK: Oxford University Press.
- Coomes, O. T., S. J. McGuire, E. Garine, S. Caillon, D. McKey, E. Demeulenaere, D. Jarvis, G. Aistara, A. Barnaud, P. Clouvel, L. Emperaire, S. Louafi, P. Martin, F. Massol, M. Pautasso, C. Violon, and J. Wencélius. 2015. "Farmer Seed Networks Make a Limited Contribution to Agriculture? Four Common Misconceptions." *Food Policy* 56: 41–50.
- Dalberg Global Development Advisors. 2012. *Ethiopian Seed Enterprise Strategy Refresh*. Addis Ababa: ATA/Dalberg.
- David, C. 2006. *The Philippine Hybrid Rice Program: A Case for Redesign and Scaling Down*. PIDS Research Paper 2006-03. Makati City, Philippines: Philippine Institute for Development Studies.
- Day-Rubenstein, K., P. Heisey, R. Shoemaker, J. Sullivan, and G. Frisvold. 2005. *Crop Genetic Resources: An Economic Appraisal*. USDA Economic Research Service (ERS) Economic Information Bulletin 2. Washington, DC: ERS.
- de Boef, W. S., H. Dempewolf, J. M. Byakweli, and J. M. M. Engels. 2010. "Integrating Genetic Resource Conservation and Sustainable Development into Strategies to Increase the Robustness of Seed Systems." *Journal of Sustainable Agriculture* 34 (5): 504–531.
- De Groote, H., Z. Gitonga, S. Mugo, and T. S. Walker. 2015. "Assessing the Effectiveness of Maize and Wheat Improvement from the Perspectives of Varietal Output and Adoption in East and Southern Africa." In *Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*, edited by T. S. Walker and J. Alwang. Wallingford, UK: CABI.
- De Groote, H., Z. Gitonga, M. Smale, D. Asare-Marfo, E. Kasuta, E. Birol, and K. Sonder. 2014. *Smallholder Farming and Crop Variety Choice: Maize Variety Choice in Zambia*. HarvestPlus Research for Action Paper 3. Washington, DC: HarvestPlus.
- De Jonge, B., and P. Munyi. 2017. *Creating Space for "Informal" Seed Systems in a Plant Variety Protection System That Is Based on UPOV 1991*. KIT Working Paper 2017-7. Amsterdam: KIT.

- Deu, M., E. Weltzien, C. Calatayud, Y. Traoré, D. Bazile, E. Gozé, G. Trouche, and K. V. Brocke. 2014. “How an Improved Sorghum Variety Evolves in a Traditional Seed System in Mali: Effects of Farmers’ Practices on the Maintenance of Phenotype and Genetic Composition.” *Field Crop Research* 167: 131–142.
- Diallo, M. 2009. “Diagnostic Study of Farmers’ Seed Quality and Variety Preference in Southern Mali.” PhD dissertation, Michigan State University, East Lansing, MI.
- Duvick, D. 1984. “Genetic Diversity in Major Farm Crops on the Farm and in Reserve.” *Economic Botany* 38: 161–78.
- Evenson, R. E., and D. Gollin. 2003. “Assessing the Impact of the Green Revolution, 1960 to 2000.” *Science* 300 (5620): 758–762.
- Fan, S. 2000. “Research Investment and the Economic Returns to Chinese Agricultural Research.” *Journal of Productivity Analysis* 14 (2): 163–182.
- Fan, S., P. Hazell, and S. Thorat. 2000. “Government Spending, Growth, and Poverty in Rural India.” *American Journal of Agricultural Economics* 82 (4): 1038–1051.
- Fan, S., and P. G. Pardey. 1997. “Research, Productivity, and Output Growth in Chinese Agriculture.” *Journal of Development Economics* 53 (1): 115–137.
- FAO (Food and Agriculture Organization of the United Nations). 2006. *Quality Declared Seed System*. FAO Plan Production and Protection Paper 185. Rome: FAO. <http://www.fao.org/3/a-a0503e.pdf>.
- . 2011. “Strengthening Seed Systems: Gap Analysis of the Seed Sector.” Item 3.3 of the Provisional Agenda, Commission on Genetic Resources for Food and Agriculture, 13th Regular Session, Rome, July 18–22.
- Feder, G., R. E. Just, and D. Zilberman. 1985. “Adoption of Agricultural Innovations in Developing Countries: A Survey.” *Economic Development and Cultural Change* 33 (2): 255–298.
- Feder, G., and D. Umali. 1993. “The Adoption of Agricultural Innovations: A Review.” *Technological Forecasting and Social Change* 43: 215–239.
- Fernandez-Cornejo, J. 2004. *The Seed Industry in U.S. Agriculture: An Exploration of Data and Information on Crop Seed Markets, Regulation, Industry Structure, and Research and Development*. Agricultural Information Bulletin 786. Washington, DC: US Department of Agriculture.
- Foster, A. D., and M. R. Rosenzweig. 2010. “Microeconomics of Technology Adoption.” *Annual Review of Economics* 2 (1): 395–424.
- FTF (Feed the Future). 2015. “e-Verification of Agricultural Inputs: Progress in Uganda.” FTF/Agrilinks presentation. Accessed May 2017. <https://agrilinks.org/sites/default/files/resource/files/e-Verification%20presentation.pdf>.
- Fuglie, K. O., P. W. Heisey, J. L. King, C. E. Pray, K. Day-Rubenstein, D. Schimmelpfennig, S. L. Wang, and R. Karmarkar-Deshmukh. 2011. *Research Investments and Market Structure in the Food Processing, Agricultural Input, and Biofuel Industries Worldwide*. Economic Research Report 130. Washington, DC: Economic Research Service.
- Gerhart, J. 1975. “The Diffusion of Hybrid Maize in Western Kenya.” PhD dissertation, Princeton University, Princeton, N.J. Abridged by CIMMYT. Mexico City: CIMMYT.
- Gildemacher, P., W. Kleijn, D. Ndung’u, I. Kapran, J. Yogo, R. Laizer, D. Nimpagritse, A. Kadeoua, D. Karnja, C. Simbashizubwoba, A. Ntamavukiro, O. Niangado, P. Oyee, A. N. Chebet, D. Marandu, E. Minneboo, G. Gitu, S. Walsh, and S. Kubgei. 2017. *Effective Seed Quality Assurance*. KIT Working Paper 2017-2. Amsterdam: KIT.
- Gisselquist, D. 2016. “Harmonizing Seed Regulations to World Best Practice: Variety Introduction.” Presentation at the “Seed for All” seminar, World Bank, Washington DC, April 27.
- Gisselquist, D., and C. Pray. 1999. *Deregulating Technology Transfer in Agriculture: Reform’s Impact on Turkey in the 1980s*. World Bank Policy Research Working Paper 2086. Washington, DC: World Bank.

- Gisselquist, D., C. E. Pray, L. Nagarajan, and D. J. Spielman. 2013. "An Obstacle to Africa's Green Revolution: Too Few New Varieties." Social Science Research Network mimeo. Accessed May 2017. <http://dx.doi.org/10.2139/ssrn.2263042>.
- Goldschagg, E. 2016. "South Africa's Approach to Variety Acceptance and Seed Quality Control." Presentation at the "Seed for All" seminar, World Bank, Washington DC, April 27.
- GRDC (Grains Research and Development Council). 2011. "End Point Royalties (EPRs): Fact Sheet." Canberra: GRDC. Accessed May 2017. <http://www.seednet.com.au/documents/End%20Point%20Royalties%20Fact%20Sheet.pdf>.
- Griliches, Z. 1957. "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica* 25 (4): 501–522.
- Hartell, J., M. Smale, P. W. Heisey, and B. Senauer. 1998. "The Contribution of Genetic Resources and Diversity to Wheat Productivity in the Punjab of Pakistan." Ch. 9 in *Farmers, Gene Banks, and Crop Breeding: Economic Analyses of Diversity in Wheat, Maize, and Rice*, edited by M. Smale. Mexico, D.F.: CIMMYT; Dordrecht, the Netherlands: Kluwer Academic.
- Hassan, R. 1998. *Maize Technology Development and Transfer*. Wallingford, UK: CABI, CIMMYT, KARI.
- Hayami, Y., and V. W. Ruttan. 1971. *Agricultural Development: An International Perspective*. Baltimore: Johns Hopkins Press.
- Hazell, P. B. R. 2010. "The Asian Green Revolution." Ch. 3 in *Proven Successes in Agricultural Development: A Technical Compendium to Millions Fed*, edited by D. J. Spielman and R. Pandya Lorch. Washington, DC: International Food Policy Research Institute.
- Heisey, P. W., ed. 1990. *Accelerating the Transfer of Wheat Breeding Gains to Farmers: A Study of the Dynamics of Varietal Replacement in Pakistan*. Economics Program Research Report. Mexico, D.F.: CIMMYT.
- Heisey, P. W., and J. Brennan. 1991. "An Analytical Model of Farmers' Demand for Replacement Seed." *American Journal of Agricultural Economics* 73 (4): 1044–1052.
- Heisey, P. W., M. A. Lantican, and H. J. Dubin. 1998. "Assessing the Benefits of International Wheat Breeding Research: An Overview of the Global Wheat Impacts Study." *CIMMYT* 99: 19–26.
- Heisey, P. W., M. Smale, D. Byerlee, and E. Souza. 1997. "Wheat Rusts and the Costs of Genetic Diversity in Punjab of Pakistan." *American Journal of Agricultural Economics* 79: 726–737.
- Heemskerk, W., I. Rwomushana, E. Asiedu, J. C. Rubyogo, F. Miti, S. Traore, H. Odame, C. Lungaho, E. Maereka, D. Kiambi, S. Tindimubona, S. Dagnoko, T. Abate, R. Vernooy, C. Fadd, and L. Sperling. 2017a. *Public Variety Use Agreements*. KIT Working Paper 2017-6. Amsterdam: KIT.
- Heemskerk, W., I. Rwomushana, E. Asiedu, J. C. Rubyogo, F. Miti, S. Traore, H. Odame, C. Lungaho, E. Maereka, D. Kiambi, S. Tindimubona, S. Dagnoko, T. Abate, R. Vernooy, C. Fadda, and L. Sperling. 2017b. *Access to Foundation Seed of Varieties in the Public Domain*. KIT Working Paper 2017-5. Amsterdam: KIT.
- Herpers, S., R. Vodouhe, M. Halewood, and B. De Jonge. 2017. *The Support for Farmer-led Seed Systems in African Seed Laws*. KIT Working Paper 2017-9. Amsterdam: KIT.
- Holden, S., and M. Fisher. 2015. "Subsidies Promote Use of Drought Tolerant Maize Varieties Despite Variable Yield Performance under Smallholder Environments in Malawi." *Food Security* 7: 1225–1238.
- Hu, R., Q. Liang, C. Pray, J. Huang, and Y. Jin. 2011. "Privatization, Public R&D Policy, and Private R&D Investment in China's Agriculture." *Journal of Agricultural and Resource Economics* 36 (2): 416–32.
- IFPRI/IDS (International Food Policy Research Institute/Innovative Development Strategies). 2012. Pakistan Rural Household Panel Survey 2012. Dataset. Washington, DC: International Food Policy Research Institute; Islamabad, Pakistan: IDS.
- IRRI (International Rice Research Institute). 2014. "Bangladesh, India, and Nepal Sign Historic Agreement in the Evaluation of Rice Varieties." Accessed August 2015. <http://irri-news.blogspot.com/2014/10/bangladesh-india-and-nepal-sign.html>.

- Jack, K. 2013. *Market Inefficiencies and the Adoption of Agricultural Technologies in Developing Countries*. White paper prepared for the Agricultural Technology Adoption Initiative. Cambridge, MA: J-PAL; Berkeley, CA: CEGA. Accessed September 2015.  
<https://www.povertyactionlab.org/sites/default/files/publications/ATAI%20Review%20Paper%20May%202013.pdf>.
- Jayne, T. S., and S. Rashid. 2013. "Input Subsidy Programs in Sub-Saharan Africa: A Synthesis of Recent Evidence." *Agricultural Economics* 44 (6): 547–562.
- Jin, S., J. Huang, R. Hu, and S. Rozelle. 2002. "The Creation and Spread of Technology and Total Factor Productivity in China's Agriculture." *American Journal of Agricultural Economics* 84: 916–930.
- Johnson, D. G., and R. I. Gustafson. 1963. *Grain Yields and the American Food Supply: An Analysis of Yield Changes and Possibilities*. Chicago: University of Chicago Press.
- Johnston, B., and J. Mellor. 1961. "The Role of Agriculture in Economic Development." *American Economic Review* 51 (4): 566–593.
- Kassie, G. T., O. Erenstein, W. Mwangi, J. MacRobert, P. Setimela, and B. Shiferaw. 2013. "Political and Economic Features of the Maize Seed Industry in Southern Africa." *Agrekon* 52 (2): 104–127.
- Kolady, D. E., and W. Lesser. 2009. "But Are They Meritorious? Genetic Productivity Gains under Plant Intellectual Property Rights." *Journal of Agricultural Economics* 60 (1): 62–79.
- Krishna, V., D. J. Spielman, P. C. Veettil, and S. Ghimire. 2016. "Exploring the Supply and Demand Factors of Varietal Turnover in Indian Wheat." *Journal of Agricultural Science* 154 (2): 258–272.
- Kuteya, A. N., C. Lukama, A. Chapoto, and V. Malata. 2016. *Lessons Learnt from the Implementation of the E-voucher Pilot*. Policy Brief 81. Lusaka, Zambia: Indaba Agricultural Policy Research Institute.
- Langyintuo, A. S., W. Mwangi, A. O. Diallo, J. MacRobert, J. Dixon, and M. Banziger. 2010. "Challenges of the Maize Seed Industry in Eastern and Southern Africa: A Compelling Case for Private-Public Intervention to Promote Growth." *Food Policy* 35 (4): 323–331.
- Lipton, M., with R. Longhurst. 1989. *New Seeds and Poor People*. London: Routledge.
- Louwaars, N. P., W. S. de Boef, and J. Edeme. 2013. "Integrated Seed Sector Development in Africa: A Basis for Seed Policy and Law." *Journal of Crop Improvement* 27: 186–214.
- Magurran, A. E. 1988. *Ecological Diversity and Its Measurement*. Princeton, NJ: Princeton University Press.
- Mason, N. M., and J. Ricker-Gilbert. 2013. "Disrupting Demand for Commercial Seed: Input Subsidies in Malawi and Zambia." *World Development* 45: 75–91.
- Mason, N. M., and M. Smale. 2013. "Impacts of Subsidized Hybrid Seed on Indicators of Economic Well-Being among Smallholder Maize Growers in Zambia." *Agricultural Economics* 44 (6): 659–670.
- Meng, E. C. H., and J. P. Brennan, eds. 2009. *Economic Analysis of Diversity in Modern Wheat*. Enfield, NH: Science Publishers.
- Minneboo, E., P. Gildemacher, D. Ndung'u, I. Kapran, J. Yogo, R. Laizer, D. Nimpagritse, A. Kadeoua, D. Karanja, C. Simbashizubwoba, A. Ntamavukiro, O. Niangado, P. Oyee, A. N. Chebet, D. Marandu, S. Walsh, G. Gitu, and S. Kugbei. 2017. *Financing Seed Business*. KIT Working Paper 2017-3. Amsterdam: KIT.
- Minten, B., A.S. Taffesse, and P. Brown, eds. *The Economics of Teff*. Washington, DC: International Food Policy Research Institute.
- Morris, M. L., ed. 1998. *Maize Seed Industries in Developing Countries*. Boulder, CO: Lynne Rienner.
- Morris, M. L., J. Rusike, and M. Smale. 1998. "Maize Seed Industries: A Conceptual Framework." Ch. 3 in *Maize Seed Industries in Developing Countries*, edited by M. L. Morris. Boulder, CO: Lynne Rienner.
- Morris, M., V. A. Kelly, R. J. Kopicki, and D. Byerlee. 2007. *Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines*. Washington, DC: World Bank.

- Naher, F. and D. J. Spielman. 2015. "Seeding the Future: An Analysis of Seed System Development in Bangladesh." Unpublished mimeo.
- Napasintuwong, O. 2014. *Maize Seed Industry in Thailand: Development, Current Situation, and Prospects*. ReSAKSS Asia Policy Note 04. Washington, DC: International Food Policy Research Institute.
- Naseem, A., J. F. Oehmke, and D. E. Schimmelpfennig. 2005. "Does Plant Variety Intellectual Property Protection Improve Farm Productivity? Evidence from Cotton Varieties." *AgBioForum* 8: 100–107.
- Naseem, A., D. J. Spielman, and S. W. Omamo. 2010. "Private-Sector Investment in R&D: A Review of Policy Options to Promote Its Growth in Developing-Country Agriculture." *Agribusiness* 2 (1): 143–173.
- Nazli, H., and M. Smale. 2015. "Dynamics of Variety Change on Wheat Farms in Pakistan: A Duration Analysis." *Food Policy* 59: 24–33.
- Pal, S., R. P. Singh, and M. L. Morris. 1998. "India." In *Maize Seed Industries in Developing Countries*, edited by M. L. Morris. Boulder, CO: Lynne Rienner.
- Pal, S., and R. Tripp. 2002. "India's Seed Industry Reforms: Prospects and Issues." *Indian Journal of Agricultural Economics* 57 (3): 443.
- Pandey, S., M. L. Velasco, T. Yamano, T. S. Walker, and J. Alwang. 2015. "Scientific Strength in Rice Improvement Programmes, Varietal Outputs, and Adoption of Improved Varieties in South Asia." In *Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*, edited by T. S. Walker and J. Alwang. Wallingford, UK: CABI.
- Perrin, R. K., K. Kunings, and L. A. Ihnen. 1983. *Some Effects of the US Plant Variety Protection Act of 1970*. Economics Research Report 46. Raleigh, NC: North Carolina State University.
- Plucknett, D. I., and N. J. Smith. 1986. "Sustaining Agricultural Yields." *BioScience* 36 (1): 40–45.
- Pray, C. E., and B. Ramaswami. 2001. "Liberalization's Impact on the Indian Seed Industry: Competition, Research, and Impact on Farmers." *International Food and Agribusiness Management Review* 2: 407–420.
- Pray, C. E., B. Ramaswami, and T. Kelley. 2001. "The Impact of Economic Reforms on R&D by the Indian Seed Industry." *Food Policy* 26: 587–598.
- Ramaswami, B., 2002. "Understanding the Seed Industry: Contemporary Trends and Analytical Issues." *Indian Journal of Agricultural Economics* 57 (3): 417–429.
- Rana, M. A. 2014. *The Seed Industry in Pakistan: Regulation, Politics, and Entrepreneurship*. Pakistan Strategy Support Program Working Paper 19. Washington, DC: International Food Policy Research Institute.
- Rana, M. A., D. J. Spielman, and F. Zaidi. 2016. "The Architecture of the Pakistani Seed System: A Case of Market-Regulation Dissonance." Ch. 5 in *Agriculture and the Rural Economy in Pakistan: Issues, Outlooks, and Policy Priorities*, edited by D.J. Spielman, S.J. Malik, P. Dorosh, and N. Ahmed. Philadelphia: University of Pennsylvania Press.
- Rogers, E. M. 1983. *The Diffusion of Innovations*, 3rd ed. New York: Free Press.
- Schultz, T. W. 1968. *Economic Growth and Agriculture*. New York: McGraw-Hill.
- Setimela P. S., B. Badu-Apraku, and W. Mwangi. 2009. *Variety Testing and Release Approaches in DTMA Project Countries in Sub-Saharan Africa*. Harare, Zimbabwe: International Maize and Wheat Improvement Center (CIMMYT).
- Shively, G. E., and J. Ricker-Gilbert. 2013. "Measuring the Impacts of Agricultural Input Subsidies in Sub-Saharan Africa: Evidence from Malawi's Farm Input Subsidy Program." *Purdue Policy Research Institute Policy Briefs* 1, no. 1, article 4. Accessed September 2015. <http://docs.lib.purdue.edu/gpripb/vol1/iss1/>.
- Smale, M., J. Hartell, P. W. Heisey, and B. Senauer. 1998. "The Contribution of Genetic Resources and Diversity to Wheat Production in the Punjab of Pakistan." *American Journal of Agricultural Economics* 80 (3): 482–493.

- Smale, M., E. Meng, J. P. Brennan, and R. Hu. 2003. "Determinants of Spatial Diversity in Modern Wheat: Examples from Australia and China." *Agricultural Economics* 28: 13–26.
- Smale, M., N. Minot, and D. Horna. 2007. "Seed Marketing." Ch. 5 in "Seed Development Programs in Sub-Saharan Africa: A Review of Experiences," edited by N. Minot, M. Smale, C. Eicher, T. Jayne, J. Kling, and D. Horna. Unpublished manuscript. Washington, DC: International Food Policy Research Institute.
- Smale, M., and J. Olwande. 2014. "Demand for Maize Hybrids and Hybrid Change on Smallholder Farms in Kenya." *Agricultural Economics* 45: 409–420.
- Smale, M., M. P. Reynolds, M. Warburton, B. Skovmand, R. Trethowan, R. P. Singh, J. Ortiz-Monasterio, and J. Crossa. 2002. "Dimensions of Diversity in Modern Spring Bread Wheat in Developing Countries from 1965." *Crop Science* 42: 1766–1779.
- Smale, M., J. Singh, S. Di Falco, and P. Zambrano. 2008. "Wheat Breeding, Productivity, and Slow Variety Change: Evidence from the Punjab of India after the Green Revolution." *Australian Journal of Agricultural and Resource Economics* 52: 419–432.
- Spielman, D. J., D. Byerlee, D. Alemu, and D. Kelemework. 2010. "Policies to Promote Cereal Intensification in Ethiopia: A Review of Evidence and Experience." *Food Policy* 35: 185–194.
- Spielman, D. J., and A. Kennedy. 2016. "Towards Better Metrics and Policymaking for Seed System Development: Insights from Asia's Seed Industry." *Agricultural Systems* 147: 111–122.
- Spielman, D. J., D. E. Kolady, A. J. Cavalieri, and N. C. Rao. 2014. "The Seed and Agricultural Biotechnology Industries in India: An Analysis of Industry Structure, Competition, and Policy Options." *Food Policy* 45: 88–100.
- Spielman, D. J., and X. Ma. 2016. "Private Sector Incentives and the Diffusion of Agricultural Technology: Evidence from Developing Countries." *Journal of Development Studies* 52 (5): 696–717.
- Spielman, D. J., and D. K. Mekonnen. 2012. *Transforming Demand Assessment and Supply Responses in Ethiopia's Seed System and Market*. Report prepared for the Agricultural Transformation Agency. Washington, DC, and Addis Ababa: International Food Policy Research Institute.
- Spielman, D. J., and D. Mekonnen (forthcoming). "Seed Demand and Supply Responses in Ethiopia's Teff Seed System." In *Teff in Ethiopia*, edited by B. Minten and A. S. Taffesse. Washington, DC: International Food Policy Research Institute.
- Sunding, D., and D. Zilberman. 2001. "The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector." *Handbook of Agricultural Economics* 1: 207–261.
- Tripp, R. 1997. *New Seed and Old Laws: Regulatory Reform and the Diversification of National Seed Systems*. London: Intermediate Technology Publications.
- Tripp, R., and N. Louwaars. 1997. "Seed Regulation: Choices on the Road to Reform." *Food Policy* 22 (5): 433–446.
- Tripp, R., and D. Rohrbach. 2001. "Policies for African Seed Enterprise Development." *Food Policy* 26 (2): 147–161.
- Walker, T. S., and J. Alwang, eds. 2015. *Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*. Wallingford, UK: CABI.
- World Bank Group. 2016. *Enabling the Business of Agriculture 2016: Comparing Regulatory Good Practices*. Washington, DC.

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