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An Empirical Examination of the Dynamics of Varietal Turnover in Indian Wheat

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ABSTRACT

The productivity gains associated with improved cultivated varieties (cultivars) tend to break down over time as they lose the genetic advantages conferred by breeding. Cultivar depreciation, in turn, can increase the vulnerability of resource-poor households to risks associated with biotic and abiotic stresses. Efforts to address this challenge through plant breeding efforts tend to fail if varietal turnover rates are low—a problem that is particularly acute among smallholders in many developing countries. This paper addresses the challenge of increasing the rate of varietal turnover to prevent depreciation of improved cultivars over time. It examines the supply of and demand for improved cultivars of wheat in India to illustrate this challenge in a unique manner, combining national-level data on breeder seed production with primary data on cultivar adoption. The analyses show that the rate of varietal turnover for wheat has slowed in India from an average of 9–10 years a decade ago to 13–14 years in 2010. By focusing on a sample of farmers and villages in Haryana, where seed and information networks are relatively well developed, the study finds that wheat farmers still prefer cultivars that were released 9–10 years ago. The results indicate that while wheat breeding and seed delivery systems may be the primary causes of this slowdown in varietal turnover, many social and economic factors at the household and village levels further slow turnover. This finding suggests that many of the constraints to technology adoption and wheat productivity growth identified 40 years ago during the Green Revolution persist today. In the face of emerging production risks ranging from new pathogens to climate change, greater investment is required to accelerate varietal turnover at the farm level as a means of sustaining wheat yield growth, reducing losses to various stresses, and protecting rural livelihoods.

Keywords: cultivar improvement; agricultural research and development; technology adoption; seed systems; wheat; India

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1. INTRODUCTION

Frequent replacement of cultivated crop varieties (cultivars) with new and improved ones is a critical means of simultaneously increasing yields and reducing the potential damage posed by evolving and newly emergent pests, diseases, and abiotic stresses. For many small-scale, resource-poor households in developing countries, cultivar replacement is also a critical means of increasing farm incomes and reducing livelihood vulnerability (Lipton and Longhurst 1985). This is especially true for crops with limited genetic diversity and crops that tend to lose resistance to pests and diseases over time (Brennan and Byerlee 1991; Heisey and Brennan 1991; Heisey 1990).

While many smallholders throughout the developing world have benefited from the introduction of *first-generation* Green Revolution cultivars that replaced lower-yielding landraces, adoption of second- and third-generation cultivars offering improvements in yield, output quality, and stress resistance seems now to be occurring at a much slower pace (Dixon et al. 2006). One reason may be that cultivar replacement typically requires farmers to purchase new seed, and their willingness to pay for new seed depends on a number of social and economic factors, including price—not only of the seed itself, but also of the complementary inputs and of the output itself when sold in the market—and the opportunity costs associated with saving seed from the previous harvest as a substitute for purchasing. Other reasons include more traditional, institutional, and technical factors such as access to credit and technological information (Feder et al. 1985).

This study examines the factors affecting wheat varietal turnover in India. Wheat is one of the main food staples in India, ranking second to rice in both domestic production and consumption. The crop was cultivated across more than 29.9 million hectares during 2011/2012 (India, DWR 2013). Wheat is also a main source of energy in the average Indian diet, accounting for 38 percent of calories from cereals for rural households in India (NSSO 2011, 2012). Despite the economic relevance of the crop, both seed replacement and varietal turnover are low among Indian farmers. Only a small portion of wheat seed is purchased by farmers each year. Specifically, only 18 percent of wheat seed was replaced in 2006, with the rest accounted for by farmer-saved seed (SeedNet India 2012). The problem posed by this low rate of varietal turnover is exacerbated by a deficit of high-quality seed (Singh and Chand 2011). These facts suggest that only a few farmers are benefiting from efforts to breed the improved wheat cultivars that are necessary to increase yields and resistance to biotic and abiotic stresses.

More to the point, while the semi-dwarf and rust-resistant cultivars introduced during the Green Revolution may have dramatically increased the compound annual growth rate of wheat yields to 3.8 percent during the period 1968–1988, that rate fell to 1.5 percent during 1989–2008 (Kolady, Spielman, and Cavalieri 2012; Chauhan et al. 2012). A part of this decline may be attributed to a declining rate of varietal turnover. In the late 1990s, the average varietal age of wheat in India—measured in number of years weighted by the quantity of seed produced by variety—was between 12 and 14 years (Pingali 1999). By comparison, the average varietal age of wheat globally was just 7 years during the same period, and in high-replacement regions such as the Yaqui Valley in Mexico, as low as 4 years (Doss 2003). Wheat varietal aging in India not only falls well below international levels but is also estimated to be about twice the ideal age required to reduce the risks associated with wheat rust (Pingali 1999). Reversal of this trend is a major priority of the government of India under the National Food Security Mission (NFSM 2012) and a stated goal of the national agricultural research system (DWR 2011). But efforts to develop better-performing cultivars and encourage their adoption among farmers to reverse this trend require more than simply greater investment in endeavors to increase output from the existing systems for research, seed multiplication, dissemination, and extension. This system—predominantly run by inefficient public-sector organizations established in the 1960s and 1970s—may require more dramatic reforms.

Over the last three decades, the public research system has released more than 281 wheat cultivars in India (Waddington, Lantican, and Tripp 2012). The current cultivars are all several generations removed from the Green Revolution cultivars and diversified in terms of suitability to different agro-ecological zones and production conditions (Kundu et al. 2010). Despite these accomplishments, very few of these new-generation cultivars account for significant portions of area under wheat cultivation (Nagarajan 2005). Part of this problem is explained by the fact that subsequent generations of cultivars typically provide only modest incremental gains over the dramatic gains provided by the replacement of landraces with first-generation cultivars (Dixon et al. 2006; Byerlee and Heisey 1990). Nevertheless, there are still concerns that new wheat cultivars are not being replaced quickly enough in India. In the middle of the decade beginning in 2000, a single variety—PBW 343, released in 1996—occupied more than 6 million hectares of land in the Indo-Gangetic Plain (Joshi et al. 2007). This prevalence reflects the fact that India's wheat farmers essentially cultivate just 6 mega-cultivars, with each of them adapted to a specific agro-ecology and sharing similar traits and susceptibilities (Mohan et al. 2001). As a result, the spatial genetic diversity of Indian wheat is limited and the production system may be significantly vulnerable to biotic and abiotic stresses that can potentially put millions of farmers and food-insecure consumers at risk.

With this background in mind, this paper revisits the research on varietal turnover by analyzing the supply and demand of improved wheat cultivars in India. It begins with an analysis of national seed policies, organizations, and institutions responsible for cultivar improvement and supply. It then addresses farmers' demand for new or recently released cultivars and its determinants in a single season by examining the cultivar portfolio across landholdings captured in household data from Haryana state. Throughout, this analysis focuses on a key metric—an index of variety change proposed by Brennan and Byerlee (1991) in which the average age of cultivars grown by farmers is weighted by the area under cultivation—to measure varietal turnover. This measure, combining spatial and temporal data, is negatively related to overall varietal turnover (Smale et al. 2008).

2. WHEAT SEED SUPPLY AND DEMAND IN INDIA

There are several reasons why the wheat seed supply system remains a largely public-sector endeavor in India. The most fundamental reason is the nature of a given crop's reproductive biology. Crops such as rice and wheat are self-pollinating, which means that harvested grain from one season can be stored and used as seed in the subsequent season without significant yield deterioration. In economic terms, self-pollination also means that any benefits from research into cultivar improvement that are embodied in the seed by an innovator (that is, a progressive farmer, crop breeder, breeding program, crop science firm, or seed firm) can be almost fully appropriated by the farmer without remuneration to the innovator in the absence of a strong intellectual property rights regime. In effect, this type of market failure discourages private investment and necessitates public investment in cultivar improvement. In contrast, hybridized crops are characterized by their unique ability to exhibit heterosis, or an increase in yield, uniformity, or vigor that results from genetic contributions derived from the crossing of distinct parental lines. The economic value of hybridization is based on the fact that yield gains conferred by heterosis decline dramatically after the cultivation of the first generation (F1). This decline compels farmers to purchase new seed each season and thus provides innovators with a means of recouping the costs of research. Hybridization thus provides a low-cost mechanism with which to introduce incremental improvements on an annual or seasonal basis. Hybridization has proven lucrative for the private sector, beginning with maize in the United States during the 1930s and expanding throughout the world to include cotton, sorghum, pearl millet, rice, and many horticultural crops.

Although an extremely small amount of hybrid wheat is cultivated in India and several other countries, the level and stability of its heterosis is marginal at best, thus discouraging private investment at levels similar to those for maize, cotton, and many horticultural crops (Matuschke, Mishra, and Qaim 2007; Zehr 2001; Knudson 1990). Moreover, policy reforms introduced in the late 1980s to liberalize India's seed sector are unlikely to encourage private investment in wheat because of the issues of appropriateness noted above (Kolady, Spielman, and Cavalieri 2012). For the foreseeable future, wheat improvement in India is expected to continue through one of the developing world's largest and oldest public-sector ventures, covering germplasm conservation, breeding, seed multiplication, seed distribution, and extension (Joshi et al. 2005, 2007; Jain and Byerlee 1999). Although private companies and individuals do play a role in wheat seed multiplication and marketing (Spielman et al. 2011), the backbone of cultivar improvement in wheat—and thus of yield improvement, biotic stress resistance, and abiotic stress tolerance—remains in public-sector entities.

In the public sector, breeder seed production follows a fairly standard procedure after national and state-level estimation of seed demand. Wheat breeding, seed demand assessment, multiplication, regulation, breeder seed production, and marketing are carried out by a vast array of primarily public-sector organizations. At the center of this array is India's national agricultural research system—the Indian Council of Agricultural Research (ICAR). Under ICAR, germplasm conservation and cultivar improvement in wheat are organized by the Directorate of Wheat Research (DWR) and the All India Coordinated Wheat and Barley Improvement Project (AICWBIP), alongside various state agricultural universities (SAUs). Decisions on which wheat cultivars to produce and in what quantities are made through a closely related set of processes involving many of these organizations. State governments, in consultation with the ICAR institutes, SAUs, cooperatives, and private seed producers, forecast breeder seed demand on the basis of current market conditions and information on how the existing and new cultivars perform in terms of actual or potential yield in relevant districts and agro-climatic zones and under specific management recommendations. With this information, each state's department of agriculture is expected to undertake advance planning and prepare a prospective for seed production and distribution over a rolling five- to six-year period, which is then reviewed and compiled by the Department of Agriculture and Cooperation (DAC) under the Ministry of Agriculture (SeedNet India 2012). DAC sets seed production targets and organizes meetings to establish production plans and assess the supply situation of various organizations involved in the seed system, including the National Seed

Corporation, the state seed corporations, and the private sector. These seed producers then submit requests (*indents*) for breeder seed to ICAR institutes or their respective SAUs along with prepayment for the seed. The deadline for indents for winter *(rabi)*–season crops such as wheat is the 15th of June of each year. After receiving and compiling indents, ICAR reviews the aggregated demand figures and transmits the indents to the project directors and coordinators of DWR and AICWBIP for review and fulfillment. Ultimately, DAC makes the final decisions, based on ICAR's recommendations, on the allocation of breeder seed to seed producers.

After the breeder seed is produced based on indents, foundation and certified seed are multiplied. Wheat seed multiplication has historically been undertaken by the National Seed Corporation, the State Farm Corporation of India, and state seed corporations, although cooperative societies and proprietary firms also play a role in multiplication (Spielman et al. 2011). These same entities also manage the marketing end of the business, either directly to farmers or through intermediaries such as input retailers, cooperative societies, and progressive farmers. The market is primarily built around a high-volume, low-margin business and is highly dependent on public investment for product development.[1] Production of certified seed that is ultimately destined to famers is monitored by a joint inspection team of wheat breeders and staff from state seed certification agencies and the National Seed Corporation (Singh et al. 2011; Waddington, Lantican, and Tripp 2012).

The entire process described above is similar to production processes for wheat and other self-pollinating crops in many industrialized and developing countries. The process aims to yield a relatively accurate forecast of variety-specific seed quantities that must be supplied in response to demand, thus informing the allocation of resources to breeding activities, breeder seed production, certified seed multiplication, distribution, and marketing. However, it is reasonable to assume that demand forecasts and supply responses are determined only partly by local market intelligence on farmers' varietal preferences and expected quantities demanded. It is also likely that seed price (and the associated elasticities of supply and demand) plays a minimal role in production decisions because seed prices are relatively low, affordable to most farmers, and constant over time in real terms. Given these assumptions, demand and supply estimates rely much more on information about historical trends, production capacity, and good guesswork. Estimates also depend on the government's seed policy on and priorities for the introduction of new wheat cultivars, for instance, cultivars that are resistant to a particular type of rust or other biotic stresses.

It is for this reason that this analysis treats official demand and supply estimates as a decent measure of the effective demand for wheat seed and, implicitly, new and improved wheat cultivars. Central to this assumption is the idea that wheat seed demand can be divided into demand for two distinct product classes. The first product class is new seeds of the same cultivar, that is, wheat seed that is of higher quality—higher purity or germination rates—for the same cultivar that farmers have cultivated in the previous season and chosen not to save for subsequent sowing. The second product class is new seed for different cultivars, that is, wheat seed for a cultivar that embodies genetic improvements over cultivars that farmers may have cultivated in the previous season. As shown later in this paper, while it is almost impossible to disaggregate seed demand figures between these two products when using official seed demand estimates and supply figures, household-level data substantially improve analytical resolution.

At this point, it is important to also note that official seed demand estimates and supply figures probably capture less than 20 percent of all wheat seed sown in India. A large part of the remainder is primarily farmer-saved seed. Nonetheless, official figures represent the most critical means of estimating farmers' demand for higher-quality inputs that directly impact on-farm productivity and associated welfare outcomes, whether through new seed of the same cultivar or seed for a new cultivar. It is for this reason that Singh and others (2011) and Waddington, Lantican, and Tripp (2012) argued that official figures are a fair proxy for overall varietal demand patterns across India. These measures are examined in further detail below.

[1] This situation is in contrast to the lower-volume, higher-margin business that has developed around cotton, maize, and horticulture (compare Spielman et al. 2011).

3. DATA

Data used in this study are drawn from two main sources. National-level data on breeder seed production come from AICWBIP. Farm-level data come from a survey of wheat-farming households in Haryana conducted in 2010. Although aggregate farmer demand for wheat cultivars is reflected in national breeder seed indents from the AICWBIP data, only household data can (1) distinguish between seed replacement and varietal turnover, and (2) provide a clear sense of the micro-level determinants of varietal turnover. The analysis of this combination of data makes this paper novel in shedding new light on the reasons for slow cultivar turnover in Indian wheat.

The national-level data on breeder seed indents and production cover the agricultural years 1997/1998 to 2009/2010 (with missing data for 2002/2003) and are disaggregated to the varietal level. These indents provide an estimate of the national demand for improved cultivars and can be further parsed to estimate regional demand. More importantly, because breeder seed is only produced based on indents and ultimately destined to seed producers, the size of these indents correlates closely to certified seed quantities that are ultimately sown by farmers.

The national-level breeder seed production data allow us to generate a measure that captures varietal turnover rates. Several measures have been proposed in the literature, for example, by Johnson and Gustafson (1963), Brennan (1984), and Brennan and Byerlee (1991), which differ only slightly. Here we follow Brennan and Byerlee (1991), who used the average age of wheat cultivars in production to represent varietal turnover, calculated as the average age of the top n cultivars based on when they were officially approved and released by the national seed system, weighted by the quantity of seed produced (or indents placed) for each. This measure can be calculated using the average age of the top n cultivars produced by the national breeding program, weighted by the quantity produced (or indents placed) as breeder seed. This measure is particularly useful because it assesses varietal age at an upstream point in the supply chain, that is, at the point where breeder seed is multiplied for seed producers rather than where certified seed is multiplied for farmers. Average varietal age can also be calculated in a similar manner using variety age weighted by quantity of certified seed produced by public and private seed producers. This method provides an insightful measure of the age of cultivars that are circulating in the seed market.

The household-level data are based on a household survey conducted in the state of Haryana in northwestern India. Haryana is situated in the highly productive western tracts of the Indo-Gangetic Plain and possesses a high cropping intensity level (200 percent) resulting from the crop rotation of rainy *(kharif)*–season rice followed by dry *(rabi)*–season wheat (Krishna, Mehrotra, et al. 2012). Haryana is the second-largest producer of wheat in India (after Punjab) and, compared with many other wheat-producing states, is characterized by high seed replacement and cultivar turnover rates.[2] The survey employed a stratified random sampling frame to select 323 farm households across 18 villages in three districts (Karnal, Kurukshetra, and Yamunanagar) that were cultivating wheat in 2009/2010. The stratification was done at the district level, and the sampling frame can be considered as representative of the wheat production systems of the state. Half of the villages (n = 9) were randomly selected, and half were selected purposively for participation in the Cereal Systems Initiative for South Asia (CSISA), an international collaboration that began in 2009 to accelerate cereal production and productivity growth in South Asia's most important grain baskets through contributions of new science and technology (see CIMMYT 2013). No significant difference was observed between the two groups of villages with respect to household demographics, and the village-level descriptive statistics suggest that most of the sampled villages are similar in terms of land-use patterns, cropping patterns, rotations, and proportion of population involved in agricultural production.

[2] For example, in states such as West Bengal and Bihar in the eastern Indo-Gangetic Plain, various government statistics and scholarly studies have found evidence of lower seed and variety replacement rates, as well as a limited capacity of farmers to actually identify the wheat varieties they cultivate due to reliance on farmer-to-farmer exchanges (rather than market-based purchases) of seed. See Krishna, Aravindakshan et al. (2012) and SeedNet India (2012).

Household interviews were conducted with the (typically male) heads of household and followed a structured questionnaire that covered topics including household demographics, landholdings, land allocations across crops, varietal use, production, and disposal, and other key indicators. The household interviews were accompanied by focus group discussions covering topics related to village-level characteristics such as physical infrastructure, market infrastructure, and social services. The descriptive statistics of the sampled households and villages are provided in Table 3.1.

Table 3.1 Summary statistics

Variable (description)		Mean (std. dev.)	Range	
			Minimum	Maximum
Dependent variable				
Age of varieties cultivated in the farmer's field (Difference between year of survey and year of release; years)		9.74 (4.06)	2	32
Explanatory variables				
Varietal age in village	(Average varietal age in other sample farms of a given village; years)	9.74 (1.74)	6.07	12.65
Adoption of wheat cultivars (share, 0–1) by other farmers in the village:				
(i) WH 711		0.35 (0.35)	0.00	1.00
(ii) PBW 343		0.51 (0.27)	0.00	1.00
Distance to seed market	(Average distance to wheat seed markets for the household; km)	5.52 (5.07)	0.00	30.00
Wheat area	(Area under wheat cultivation; ha)	2.77 (3.30)	0.10	23.08
Land owned	(Agricultural land owned by the household; ha)	2.78 (3.16)	0.00	24.29
Tractor ownership	(Dummy variable for households that own a tractor)	0.43	0	1
Credit taken for wheat	(Dummy variable for households using credit on wheat cultivation)	0.88	0	1
Farmer age	(Age of household head; years)	47.73 (12.92)	21	98
Education dummy	(Dummy for household heads who attained some schooling)	0.89	0	1
Level of schooling	(Schooling in years by the household head if education dummy = 1)	9.20 (3.36)	2	20
Family members in farming	(Number of family members actively involved in farming activities)	1.38 (1.18)	0	9

Source: Authors.
Note: Std. dev. = Standard deviation; km =kilometer; ha = hectare. Number of observations: 323.

We use the household-level dataset to estimate the determinants of cultivar adoption patterns. Here, the *newness* of a cultivar in the system is calculated at the farm level by using the cultivar's age (difference between year of cultivation—for instance, 2009/2010—and year of varietal release in India) weighted by acreage under its cultivation. This method allows for in-depth analysis of varietal aging as it relates to individual, household, and village characteristics that determine the adoption of improved cultivars. However, it should be noted that this measure is not at all analogous to the conventional seed replacement rate used in official figures cited earlier, nor is this study's focus on seed replacement rates.

Rather, this measure is indicative of the cultivar turnover rate of the local seed distribution system as a whole, but not that of the farm household. For example, a farmer might have recently adopted a cultivar that was released several years earlier by the public seed supply system. In this case, the cultivar is new for the household, but its adoption is still associated with a slow varietal turnover at the system level. In short, micro-level cultivar adoption data do not indicate the speed of turnover by households, but a study of adoption determinants is expected to shed light on the reasons behind the slow rate of turnover at the system (for example, state) level.

The determinants of farmer adoption of recently released cultivars include both farm-level and village-level factors. It is worth noting the wide variation in landownership and operation, and the implications of this variation, for later analysis. The land rental market is quite vibrant, with a high degree of heterogeneity in land characteristics and rental rates. In general, it is the large farmers who lease in more land to exploit the economies of scale. A census in the selected villages showed that the land owned by the leased-in farmers is 2.46 ha (against 1.87 ha by other farmer households), and they cultivate in 4.94 ha (against 1.77 ha by others) (Krishna, Mehrotra, et al. 2012). Operational landholdings and area under wheat cultivation are found to be only moderately correlated to each other; hence, both are included in the econometric analysis on varietal turnover at the farm level.

In relative terms, households in the sample are wealthy when compared with farmers in other regions of India. This is evidenced by indicators such as ownership of a tractor—a productive asset owned by 43 percent of households in the sample. It is also evidenced by the relatively limited occurrence of credit scarcity among these sampled households. This finding is in contrast to the numerous studies indicating that smallholder production is constrained by limited access to credit for the variable costs of inputs such as seed, fertilizer, machinery, or hired labor (Dixon et al. 2006; Feder et al. 1985).

4. EMPIRICAL STRATEGY

This study's empirical model draws on household data to estimate the determinants of adoption of recently released cultivars at the farm household level along the lines of Heisey and Brennan (1991). This estimation is done by calculating the varietal turnover as described earlier, whereby the average age in the seed system for a cultivar adopted by a given farmer is weighted by the area planted in each variety, that is,

$$A_i = \sum_{j=1}^{J} A_{ij} \frac{L_{ij}}{\sum L_{ij}}, \quad (1)$$

where A_i is the average age of cultivars cultivated by the *i*th household, A_{ij} is the number of years since the *j*th variety was officially released, and L_{ij} is the area under the *j*th variety on the *i*th household's farm. Each of the sample wheat farmers is associated with an average *cultivar age* that is calculated by his or her varietal portfolio during the year of the survey. This measure is simple to calculate and avoids the use of arbitrary definitions of *recent* or *older* cultivars in the seed distribution system. Further, multiple regression models are estimated with on-farm average varietal age as a function of a number of farm, household, and village characteristics. Although this measure is at the farm level, it captures two features of the (macro-level) wheat seed distribution system: the relative speed (diffusion) at which a new variety is adopted by farm households (a lower age represents a highly responding wheat varietal system with efficient dissemination) and the varietal turnover rate of the system. Further, it should be pointed out that the measure is different from the conventional seed replacement rate. Most of the sample farmers purchase seeds every year instead of relying on their own saved seeds, and they select a portfolio that includes cultivars that are released at different points in time.

We expect that certain village-level attributes can explain patterns of varietal turnover. For example, remoteness of the village from the formal seed market is included as a village-level attribute. We also consider a given village's collective receptiveness to technological change as a determining factor in encouraging varietal turnover. This effect may operate through social network effects, through the dynamics of collective action, or through any other of a number of channels (Foster and Rosenzweig 1995; Munshi 2004). To capture this potential social network effect, we consider the average age of cultivars in other farmers' fields in the village and hypothesize that this variable is positively correlated with the varietal age of individual farmers' plantings. In an alternative specification, we also consider the adoption rate of two relatively older cultivars (WH 711 and PBW 343) by other farmers in the village, with a similar expectation of positive correlation. Necessarily, these variables may be endogenous because we cannot directly infer whether the average behavior of farmers in the village influences the behavior of the individuals that make up the village, or whether the farmers in the village simply share similar individual characteristics or face similar conditions that affect their individual decisions (Manski 1993). Strong instruments, panel data, or other identification strategies (see, for example, Magnan et al. 2013; Maertens 2013; McNiven and Gilligan 2012; Bandiera and Rasul 2006; Conley and Udry 2010; Foster and Rosenzweig 2010) can be used to resolve this reflection problem, but such strategies are not available given our cross-sectional household data, thus restricting our ability to infer causality.

With respect to household attributes that might explain patterns of varietal turnover, we include a number of variables that are both consistent with our theory on adoption determinants and empirically testable. First, we expect the households with greater wealth or larger operational landholdings to cultivate varieties that have been released more recently than those cultivated by poorer households, households with smaller operational landholdings, or households that otherwise exhibit attributes such as risk aversion. The deterministic pathway is well documented in the literature: such households are likely better able to manage risks, obtain information, and cover transaction costs associated with early technology adoption (Just, Zilberman, and Rausser 1980; Feder and O'Mara 1981), and these relationships are borne out with evidence on varietal turnover (Brennan and Byerlee 1991; Smale et al.

2008). We also expect households with greater experience (represented by the age of the household head) and education (measured in terms of the years of schooling completed by the household head) to cultivate varieties that have been released more recently. This hypothesis is also consistent with the literature on technology adoption (Foster and Rosenzweig 2010; Feder et al. 1985). However, the importance of experience and education may be muted if information associated with new cultivar adoption—for example, changes required in input use or agronomic practices—is not very difficult for farmers to decipher (Duflo, Kremer, and Robinson 2008).

5. RESULTS

Before providing results from the household-level adoption estimates based on the approach detailed above, we present our analysis of the official demand estimates and supply figures for wheat seed in India.

Demand for Breeder Seed: Analysis of National-Level Data

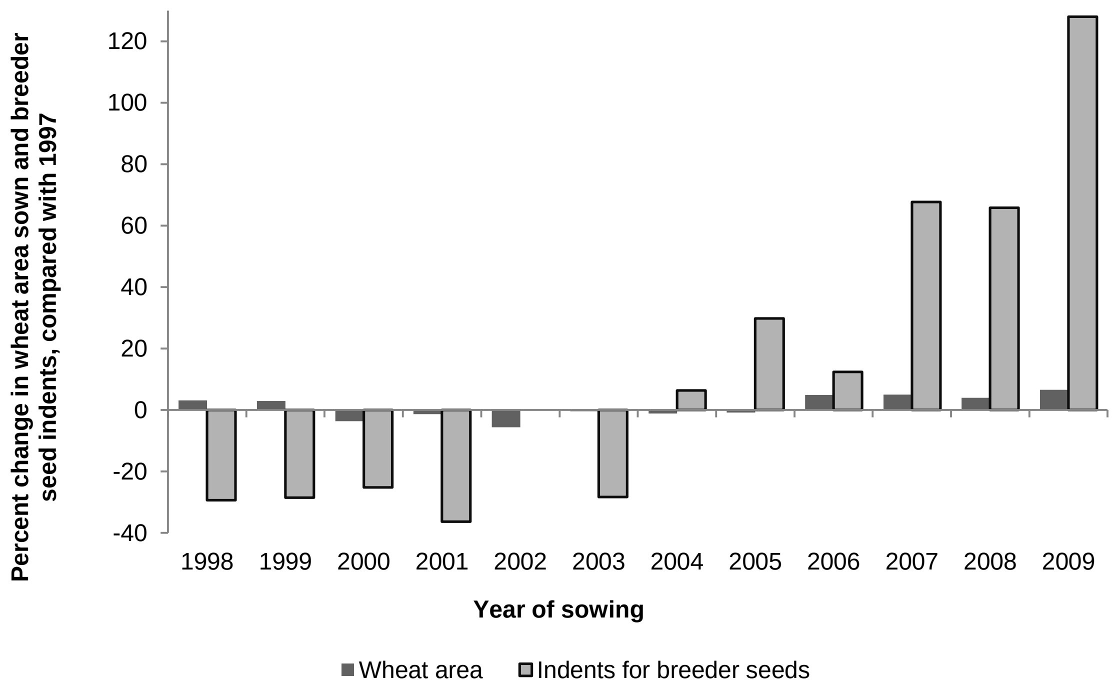
Analysis of the breeder seed indent data indicates that the average varietal age for wheat in 2011/2012 was greater than 12 years, twice the recommended varietal turnover rate (6 years). Table 5.1, along with Figure 5.1, provides a picture of the changing scenario with respect to official demand for breeder seed between 1997/1998 and 2009/2010 based on indents. The numbers indicate that demand has more than doubled over the period, increasing at a fairly constant rate. When graphed against official figures for area under wheat cultivation, we see that the growth of breeder seed demand exceeded area expansion after 2004. This suggests that the quantity of new seed demanded has been steadily increasing, which further indicates an increase in seed replacement and market purchases over the period.

Table 5.1 Indents and production of wheat breeder seed in the public sector of India

Year	Total quantity (metric tons) of		Number of cultivars under seed production	Average age (years) of top 20 cultivars for	
	Indents quoted	Seed produced		Indents quoted	Seed produced
1997/1998	1,333	1,277	90	9.57	9.00
1998/1999	942	1,226	83	9.25	9.42
1999/2000	953	1,614	86	8.31	10.57
2000/2001	998	1,684	102	8.91	8.79
2001/2002	849	1,370	106	9.06	9.47
2003/2004	956	1,763	111	9.53	8.96
2004/2005	1,418	2,184	116	12.83	12.20
2005/2006	1,730	2,533	123	13.56	13.88
2006/2007	1,498	2,491	125	13.60	13.38
2007/2008	2,235	2,875	138	14.63	14.18
2008/2009	2,210	2,896	139	13.40	13.48
2009/2010	3,039	3,489	153	12.37	12.94

Sources: AICRP, various years.
Note: Data not available for 2002/2003.

Figure 5.1 Change in wheat area and breeder seed demand over years



Source: Authors, computed from FAOSTAT (2013); AICRP, various years.
Notes: Data on seed indents not available for 2002. Changes are computed with reference to the 1997 figures.

However, does the increase in demand for new seed necessarily translate into demand for new cultivars? Here, a closer look at the numbers for breeder seed production does suggest a clear increase in varietal diversity. In 1997/1998, about 90 cultivars were under breeder seed production, and by 2009/2010 this figure had increased to more than 150. Since seeds are not usually produced for a variety with no stated indent, the increase in number of cultivars under breeder seed production suggests that India has seen (1) an increase in farmer demand for new cultivars and varietal diversity, (2) an increase in government efforts to promote new cultivars and greater varietal diversity, or (3) both.

But closer analysis of these official figures also shows a clear and increasing trend in average varietal age (Table 5.1). Prior to 2001/2002, the average varietal age for breeder seed indents was 9–10 years, as also shown by Pingali (1999). After 2005/2006, the average varietal age increased to 13–14 years. Out of the 20 most popular wheat cultivars in 2011/2012, 7 were released on or before 1997 and occupied 27 percent of total wheat area in India (Table 5.2). These findings indicate quite the opposite of what is suggested above, namely, (1) a decrease in farmer demand for new cultivars, (2) the absence of government efforts to promote new cultivars, or (3) both.

Table 5.2 Estimated area coverage of popular wheat cultivars in India in 2011/2012

Rank with respect to area under cultivation	Name of wheat variety	Year of release	Area under cultivation (thousand hectares)	National wheat area covered (%)
1	HD 2733	2001	3,828.17	12.82
2	PBW 502	2004	3,384.55	11.34
3	PBW 550	2007	3,215.59	10.77
4	DBW 17	2007	2,132.60	7.14
5	Lok 1	1982	1,902.22	6.37
6	PBW 373	1996	1,727.53	5.79
7	HUW 234	1986	1,407.97	4.72
8	GW 322	2002	1,199.41	4.02
9	Raj 4037	2003	1,172.78	3.93
10	GW 273	1998	1,166.39	3.91
11	PBW 343	1996	1,157.86	3.88
12	Raj 3765	1996	981.04	3.29
13	WH 711	2002	948.02	3.18
14	HD 2932	2006	663.62	2.22
15	GW 496	1990	622.07	2.08
16	GW 366	2007	517.68	1.73
17	HD 2864	2004	445.25	1.49
18	K 9423	2005	443.12	1.48
19	Raj 3077	1989	377.08	1.26
20	Raj 4120	2009	373.88	1.25
	Others		2,186.23	7.32
		Average cultivar age: 11.16 years*	Total area: 29,853.06 thousand hectares	

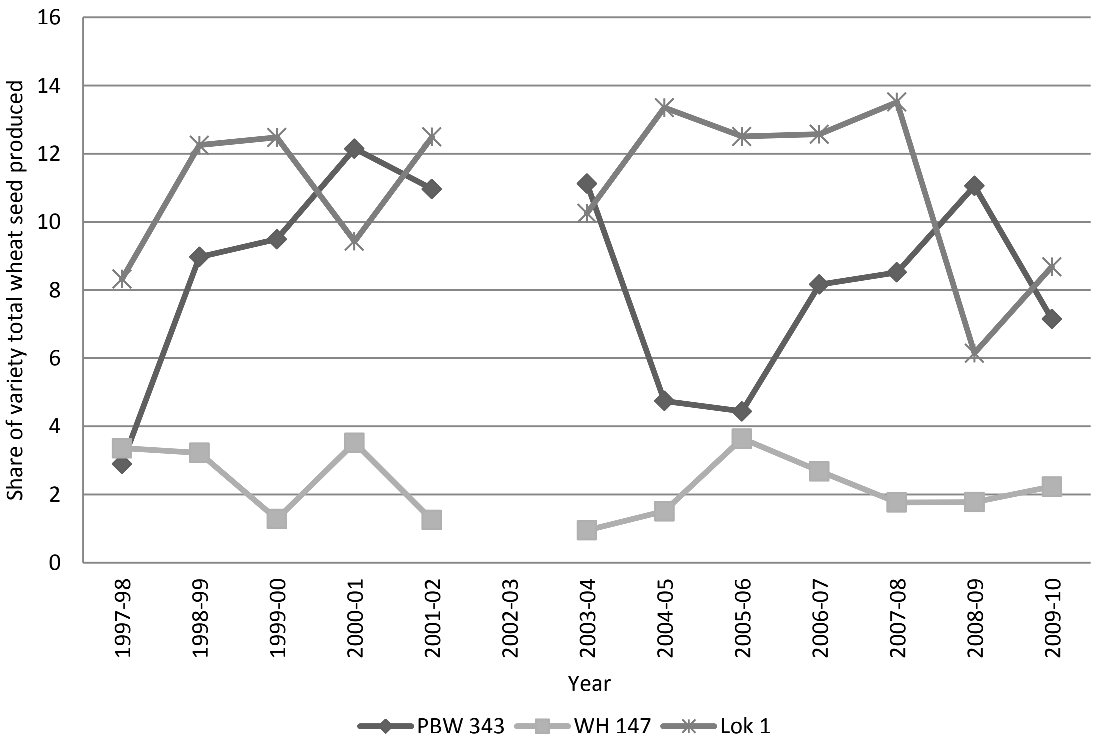
Source: DWR (2013).
Note: * For the top 20 cultivars.

To be clear, an increase in varietal diversity comes at the expense of older varieties that are replaced. The older wheat cultivars that continue to dominate breeder seed indents include PBW 343 (released in 1996) and Lok 1 (released in 1982). These two cultivars occupied the first and second ranks, respectively, in both breeder seed indents and production during most of the recent years, and together accounted for 15 percent of total seed indents in 2009/2010.[3] An even older variety—WH 147, released in 1977—also accounts for a nontrivial portion of breeder seed indents. Relatedly, there is no evidence of a consistent decline in seed indents recorded for these three cultivars during the last decade (Figure 5.2), even despite official recommendations to discourage breeder seed indents for old and rust-susceptible cultivars like PBW 343, Lok 1, and WH 147. These recommendations—when followed through with purposive reductions of breeder seed indents—constitute the national research system's main (and possibly only) means of *nudging* varietal turnover in a particular direction. This was observed, for example, with the purposive reduction of breeder seed production for Lok 1 in favor of less rust-

[3] Lok 1 is dominant in India's central zone and is popular among farmers due to its good grain quality (Mohan et al. 2001). PBW 343, on the other hand, provides a combination of traits that allows it to perform well under diverse agroclimatic conditions and is especially popular in the northwestern Indo-Gangetic Plain. Krishna, Aravindakshan, et al. (2012) reported significant yield loss associated with PBW 343 adoption in the eastern Indo-Gangetic Plain.

susceptible, newer varieties in 2007/2008 and 2009/2010 (India, DWR 2011). The scenario appears to be a response to this official intervention, at least occasionally, and the share of breeder seed production for these cultivars is found declining in some years. For example, in the 2011/2012 crop season, the highest number of indents was registered for the variety PBW 550, which was released only in 2008 (DWR 2013).

Figure 5.2 Breeder seed production of three mega-cultivars of wheat in India



Source: Estimated from AICRP, various years.
Note: Data not available for 2002/2003.

However, two issues still warrant attention. First, a surplus of breeder seed production relative to the submitted indents is often reported in the case of older varieties like Lok 1, WH 147, and Raj 3077 (the latter released in 1989), while production for some of the promising new cultivars (DBW 17, for example) was below the number of indents submitted in many years. This discrepancy in favor of overproduction of older varieties and underproduction of newer varieties poses a supply-side constraint to promoting varietal turnover. Second, the varietal demand of farm households is *sticky* toward older cultivars, making the regulatory efforts to reduce varietal age inconsistent over time. For example, after a short phase of decline in 2008/2009, the seed indents for Lok 1 are reported to be again increasing in the recent past (the 2011/2012 season) (DWR 2013), indicating that farmers may not consider the new varieties meant to replace Lok 1 as effective substitutes. Few studies examine the reasons behind this demand adhesiveness, including the potential impacts of consumption preferences.[4]

[4] Rashid et al. (2013) provided a case in which consumption preferences critically determined the success of varietal development programs: Lerma Rojo 64-A, dwarf wheat seeds imported from Mexico before the Green Revolution to improve wheat yield in India. Although the variety provided higher yields, it was rejected by farmers and consumers due to red color of the grain.

Demand for Recent Wheat Varieties: Household-Level Data from Haryana

In order to better understand farmer demand and heterogeneity in demand patterns, we now turn to the household data from Haryana and estimate the micro-level determinants of varietal turnover. Specifically, we examine individual and village attributes that affect adoption of modern (recently released) varieties and could form the basis for determining varietal indents and seed production as well as for accelerating the rate of varietal turnover in Indian wheat.

One of the potentially key determinants of choosing recently released varieties in a farmer's cultivar portfolio is landholding size, a variable that not only is positively associated with the scale of operation but also represents the asset status, creditworthiness, and often, social status of the farm household. Table 5.3 categorizes households by operational landholding size. The distribution of different classes of farms across the three study districts is similar, with the sample comprising mostly medium-sized (2–10 ha) farms (43 percent), followed by marginal (up to 1 ha) and small (1–2 ha) farms (26 percent each). The distribution of the most important cultivars (DBW 17, PBW 502, WH 711, PBW 343, and WH 542) cultivated across different farm categories is presented in Table 5.4. Farmer adoption is in tune with the secondary data on the most popular wheat cultivars of the northwestern plain zone of India (DWR 2013). The sampled households are found to cultivate varieties that were released 9.74 years ago, which is 60 percent greater than the recommended 6-year varietal turnover rate. The newest wheat varieties cultivated in farmers' fields are two years old (PBW 550 and HD 2932); the oldest is 40 years old (C 306). Less than 1 percent of sampled farmers adopted C 306 during the 2009/2010 wheat season, and even after excluding such exceptionally old and sparsely adopted varieties from the sample, the average age decreases only to 9.50 years, verifying the robustness of our estimates.

Table 5.3 Operational holding of sample farmers of Haryana

District	Number of households (percentage of wheat farmers)				
	Marginal (up to 1 ha)	**Small (1.01–2 ha)**	**Medium (2.01–10 ha)**	**Large (> 10 ha)**	**Total**
Karnal	20	25	56	7	108
	(18.52)	(23.15)	(51.85)	(6.48)	(100.00)
Kurukshetra	28	27	48	4	107
	(26.17)	(25.23)	(44.86)	(3.74)	(100.00)
Yamunanagar	37	32	36	3	108
	(34.26)	(29.63)	(33.33)	(2.78)	(100.00)
Total	85	84	140	14	323
	(26.32)	(26.01)	(43.34)	(4.33)	(100.00)

Source: Authors.
Note: ha = hectare. Table uses the intervals commonly used for farm size categorization based on operational holding in India (compare Datt and Sundharam 2000).

The rate of adoption of modern wheat varieties in Haryana, based on our sample estimates, is higher than the all-India average based on the analysis of breeder seed indents presented earlier, but it is significantly lower than the rate prevailing in many developing countries (Table 5.4). Importantly, and despite the perception that farmers in Haryana are progressive early adopters, the average varietal age does not surpass the rate recommended to avoid genetic deterioration. Within the sample, the use of recently released varieties is frequent among households operating larger farms (with average varietal age of 6.93 years), although such households represent only a minority (4 percent) of the sample.

Table 5.4 Farmer adoption of wheat cultivars in the study area

Farm size	Percentage of sample households (percentage of wheat acreage) with variety					Average age of all cultivars in years (std. dev.)
	DBW 17 ***[YR: 2006]***	**PBW 502** ***[YR: 2004]***	**WH 711** ***[YR: 2002]***	**PBW 343** ***[YR: 1996]***	**WH 542** ***[YR: 1992]***	
Marginal (*n* = 85)	4.71 (5.29)	4.71 (7.37)	40.00 (30.01)	49.41 (50.79)	3.53 (2.50)	10.11 (5.21)
Small (*n* = 84)	8.33 (10.93)	3.57 (11.90)	36.90 (33.66)	47.62 (36.61)	1.19 (0.64)	10.32 (5.78)
Medium (*n* = 140)	26.43 (12.87)	16.43 (8.59)	31.43 (18.15)	53.57 (31.13)	10.71 (6.68)	9.45 (4.58)
Large (*n* = 14)	42.86 (38.42)	21.43 (9.47)	28.57 (12.63)	42.86 (23.42)	0.00 (0.00)	6.93 (4.79)
Overall (*n* = 323)	16.72 (16.40)	10.22 (9.24)	34.98 (20.99)	50.46 (32.41)	5.88 (4.05)	9.74 (4.06)
p-value*	0.00	0.00	0.15	0.70	0.06	

Source: Authors.

Notes: *YR*: year of variety released. Std. dev. = Standard deviation. * Refers to the p-value derived from χ^2 test (with trend).

Several results emerge from the estimation of the determinants of average age of wheat varieties in sampled farmers' fields. First, the average age of wheat cultivars in the fields of other farmers in the village is found to be positively associated with the average age of household *i*'s varieties, as shown in Model 1 of Table 5.5. This effect is more robust with respect to PBW 343 in Model 2, suggesting the possibility that strong social networks are closely associated with older varietal portfolios, although inferences are subject to the limitations discussed earlier. Second, the distance to the nearest seed market is insignificantly related to a household's average varietal age, suggesting that spatial and infrastructural factors may not play a significant role in varietal adoption in Haryana. This stands to reason given the state's relatively small size and good road network, factors that are not true of other Indian states.

Third, although asset ownership—landholding size and tractor ownership—is not a statistically significant determinant of average varietal age, the area of wheat under cultivation is both significant and negative in sign. Specifically, a 1 ha increase in wheat area is associated with a reduction in average varietal age of 0.28 years. The potential mechanism for this association is fairly clear: farmers with larger investments in wheat cultivation may be more willing or able to experiment with, and eventually adopt, more recent varieties.

Fourth, the coefficient estimate for share of household members involved in farming is statistically significant and positive in all the models estimated. One possible explanation is that the number of household members that are active in farming reflects the household's relative poverty status, such that poorer households rely more on own-household labor and are also more risk averse in varietal turnover decisions. Another, more generic, explanation is that if the decision to cultivate a new variety requires consensus among key family members who are involved in farming, then opinion formation and decision-making become more difficult and time consuming, causing households to forgo varietal turnover in order to minimize conflict.

Table 5.5 Determinants of average age of wheat cultivars on-farm

Variable	Coefficient (robust standard error)		
	Model 1	**Model 2**	**Model 3**
Varietal age in village	0.311*		
	(0.168)		
Adoption of wheat cultivars by other farmers in the village:			
(i) WH 711		3.454*	
		(2.080)	
(ii) PBW 343		5.262***	
		(1.886)	
Distance to seed market	-0.028	-0.014	-0.001
	(0.043)	(0.043)	(0.045)
Wheat area	-0.260***	-0.269***	-0.277***
	(0.094)	(0.095)	(0.097)
Land owned	-0.080	-0.068	-0.043
	(0.100)	(0.099)	(0.100)
Tractor ownership	-0.450	-0.331	-0.394
	(0.492)	(0.493)	(0.511)
Credit taken for wheat	-0.587	-0.648	-0.490
	(0.689)	(0.684)	(0.703)
Farmer age	0.002	0.004	0.006
	(0.017)	(0.017)	(0.018)
Education dummy	-1.565	-1.649	-1.339
	(1.319)	(1.312)	(1.353)
ln(level of schooling)	0.894*	0.889*	0.787
	(0.547)	(0.544)	(0.557)
Family members in farming	0.494***	0.517***	0.468***
	(0.180)	(0.179)	(0.182)
Fixed effects	District level	District level	Village level
Adjusted R^2	0.17	0.18	0.19

Source: Authors.

Notes: Dependent variable is average age (year) of wheat cultivars cultivated on-farm, weighted by their share of cultivated area. Varietal age is calculated as the difference between year of cultivation and year of official varietal release. *, **, *** denotes estimates are significant at the 10 percent, 5 percent, and 1 percent level, respectively.

Finally, we explore education and schooling. When the years of schooling attained by the head of the household is directly included in the model, it shows no significant effect. Further examination reveals that although educated farmers generally use varieties released more recently, there is a negative relationship between years of schooling attained and age of the varieties adopted. To address this contradiction, we construct a dummy variable for strictly positive values of schooling and a term that interacts this dummy variable with the logarithm of years of schooling, following Battese (1997). The coefficient of the interaction term is weakly significant in Models 1 and 2, while the dummy variable is insignificant. Although the level of significance is reduced in the model with village-level fixed effects, the magnitude of impact is still comparable. These results are somewhat contrary to the expectation and existing adoption literature.[5]

[5] Several explanations seem feasible. Some level of education is necessary to obtain information from mass media such as newspapers. However, a higher level of education may simply be unimportant as a determinant of varietal turnover in an area where technology adoption—specifically, adoption of new cultivars—has been central to production practices for more than four decades. Alternatively, preferences for the older mega-cultivars may be *sticky* in that well-educated farmers are fully aware of the possibly high switching costs associated with newly introduced cultivars, and hence unwilling to incur them.

Discussion

These analyses of national and household-level data raise several issues. It is clear that despite the Indian government's goals of increasing varietal turnover rates, wheat farmers continue to demand and cultivate the age-old varieties. The persistence and prominence of these varieties pose critical questions regarding the efficacy of the research, development, and delivery system in catering to farmer demand for certain key varietal attributes. Specifically, it can be argued that the strategy of reducing breeder seed production irrespective of varietal demand patterns can easily backfire if farmers reject newer varieties in favor of older ones and revert to a supply system that relies increasingly on farm-saved or locally exchanged seed. Given that the public sector is the largest player in the wheat breeding, production, and distribution system, and given the nonmarket mechanisms used to assess varietal demand, national-level secondary data on indents may be insufficient to capture the true varietal preference exhibited at a micro level.[6] Clearly, additional data and analysis are needed to uncover information about varietal demand and heterogeneity in demand patterns, and to enhance the public sector's capacity to supply improved wheat varieties to farmers in India.

This study's efforts to uncover information about varietal demand and heterogeneity in demand patterns in Haryana should be taken as an illustration of one way that the public sector could enhance the supply of improved wheat varieties to farmers in India. Its examination of farm-level data reveals the following patterns. First, there may be social network effects at play that effectively repress varietal turnover, although inferences of causality cannot be made with these data. Second, the scale of wheat cultivation is a stronger determinant of varietal turnover than is asset ownership. Third, reliance on own-household labor tends to constrain varietal turnover. These findings may suggest that extension programs and other distribution mechanisms that aim at accelerating varietal turnover may need to invest in better understanding the role of social network effects, particularly with respect to alternative approaches to disseminating information about new varieties, for example, through demonstration plots, agricultural fairs, mass media, and other channels. These programs may also need to invest in reaching out to poorer households more directly, or at least rethink the commonly accepted strategy that larger, more progressive farmers will effectively demonstrate the adoption of new varieties and convince smaller, more risk-averse farmers to follow suit. Finally, these programs may need to invest more in understanding why the demand for older cultivars remains so sticky, for example, whether educated or otherwise knowledgeable farmers stick with older varieties because of some specific varietal qualities (such as consumption qualities of the grain), and if so, whether wheat breeding programs might need to focus more on developing cultivars with these attributes than on pursuing yield criteria alone.

[6] As mentioned earlier, since wheat is an open-pollinated crop, own-seed production at farms for older preferred cultivars such as PBW 343, Lok 1, WH 147, and others poses serious errors in seed demand estimation using indents.

6. CONCLUSION

This paper argues that the high rate of varietal diversity that has been increasing in recent years has not translated into higher varietal turnover in farmers' fields. The varietal turnover is far behind the optimal level recommended to avoid genetic deterioration, which could potentially expose the crop to biotic and abiotic stresses, especially in the face of threat posed by the stem-rust race Ug99. The study identifies three possible reasons for poor varietal turnover in Indian wheat: First, the research system may not be efficiently identifying and translating farmer preferences for varietal attributes into cultivars that they are willing and able to adopt. Second, the seed production system may not be producing what farmers actually demand due to a poor seed demand assessment system. Third, extension programs and other distribution mechanisms may be underperforming in their efforts to convey the genetic superiority of improved varieties to farmers.

In both absolute and relative terms, public investment remains the salient feature of India's wheat breeding, production, and distribution system since the Green Revolution era. Private-sector involvement is limited mostly to multiplying and supplying certified seeds, and the combination of crop reproductive biology and India's intellectual property rights regime will not change this situation anytime soon. Thus, the rate of wheat varietal turnover is largely determined by policies, investments, and programs of the public sector.

Given that Haryana—the focus of this household-level analysis—is one of India's breadbaskets and is populated by relatively progressive farmers with access to improved varieties, it is likely that similar conclusions about low rates of wheat varietal turnover can be drawn for other states using data from farm household surveys. The negative impacts of a low rate of varietal turnover are nontrivial for India: cultivar depreciation can increase the vulnerability of resource-poor households to risks associated with biotic and abiotic stresses. Greater consideration of participatory breeding approaches to wheat variety improvement may be warranted. Greater public investment in research and extension programs that aim at accelerating varietal turnover may be desirable, especially if they leverage both national and international expertise in areas such as participatory plant breeding and seed market development. Further exploration of the role that private firms might play in research, development, and delivery of improved wheat varieties may also be an area for consideration. Finally, additional studies designed to increase the methodological rigor with which relationships between varietal turnover and household- and village-level characteristics are examined is critically important to further the research in this field.

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