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Melinda Smale
Hina Nazli

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Melinda Smale[1] and Hina Nazli[2]

ABSTRACT

The irrigated areas of Punjab, Pakistan, were the locus of the Green Revolution in wheat, where all varieties grown today are modern. Despite that transformation, many rural Pakistanis still suffer from malnutrition, including zinc deficiency. Zinc-biofortified wheat varieties are one approach for alleviating this problem among poor farming households who do not have access to enriched food products. To promote new varieties effectively, decision makers need to understand why some varieties become more popular than others, especially for this target group.

This paper applies duration analysis to identify the factors that shorten the time until a farmer replaces one modern variety with another, and tests hypotheses concerning two salient themes of the Green Revolution: farm size differences and the role of information in farmer-to-farmer seed diffusion. Findings indicate that the time span between changing varieties averages only four years, but is shorter on larger farms. Factors that speed variety change also differ by farm size. Extension and media sources of information are significant among larger farmers relative to social information, which is more important among marginal farmers. Traits related to consumption quality speed variety change among smaller-scale farmers, who both sell and consume their wheat. Higher yields drive variety change among the most subsistence-oriented, marginal farmers.

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1 Department of Agricultural, Food and Resource Economics, Michigan State University. msmale@msu.edu (703-231-8492). Corresponding author.
2 Pakistan Strategy Support Program of the International Food Policy Research Institute (IFPRI) and Innovative Development Strategies (IDS), Pakistan. hinanazli@idspak.com

CONTENTS

I. INTRODUCTION

The irrigated areas of Pakistan's Punjab Province are the historical locus of the Green Revolution in wheat. Known in the narrowest sense by the swift diffusion of short-statured, higher-yielding wheat varieties during the 1960s, Pakistan's Green Revolution also entailed public investments in irrigation canals and tubewells, fertilizers, and market development. Technical change generated welfare benefits not only among farmers who adopted improved varieties and fertilizers in high-productivity environments like those of Punjab (Renkow 2000), but also among laborers and consumers, transforming the wheat economy and rural society (Djurfeldt et al. 2005; Hazell 2010; Otsuka and Larson 2012). Despite such acclaimed progress, large numbers of Pakistanis continue to live in poverty, suffering from malnutrition and micronutrient deficiencies.

Zinc deficiency illustrates one aspect of this problem. According to the *Pakistan National Nutrition Survey 2011*, the average prevalence of zinc deficiency is relatively high in Pakistan, and is more severe among women and children (GOP 2012). Nearly 41.6 percent of non-pregnant women, 48.3 percent of pregnant women, and 36.5 percent of children are zinc-deficient. Zinc plays a crucial role in resistance to disease, diabetes control, wound healing, digestion, reproduction, and physical growth.

One way to reduce zinc deficiency is to introduce higher zinc content into wheat, which is still the most important starchy staple in the Pakistani diet. Wheat is grown by a majority of farmers and consumed by almost all rural and urban households. The average Pakistani household spends nearly 15 percent of its monthly income on wheat and wheat products (GOP 2011a). To reach poorer people in remote rural areas who do not have access to zinc-enriched food or zinc supplements, scientists have proposed the fortification of popular wheat varieties. The costs and benefits of this approach have been assessed ex ante by Meenakshi et al. (2010).

To design effective programs for introducing high-zinc varieties, the Government of Pakistan, private seed sector, and international research partners need to understand the process of wheat variety adoption and diffusion today, and how this process differs by target group. Decades after the Green Revolution, most farmers already grow modern ("high-yielding") varieties of wheat. In today's Pakistan, "adoption" refers specifically to a farmer's replacement of one modern variety with a more recently released modern variety, rather than to the replacement of tall-statured varieties or farmers' landraces with newer types, as was the case in the Green Revolution.

Previous research has documented that the slow rate of variety replacement by farmers has posed a major challenge for wheat production in Pakistan (e.g., Heisey, 1990; Farooq and Iqbal 2000; Iqbal et al. 2002). One consequence has been the concentration of wheat-cultivated area in a few popular varieties, which depresses yield potential and aggravates the crop's vulnerability to plant disease, including endemic strains of wheat rust (Heisey et al. 1997). For example, in 1997, six years after its release, Inqilab was sown across an estimated 4.22 million hectares in Pakistan alone (Smale et al. 2002). Inqilab remained the most popular wheat variety until the release of Seher in 2006. A recent stochastic frontier analysis by Battese et al. (2014) confirms that slower variety replacement reduces the technical efficiency of wheat production in the Punjab of Pakistan.

Several salient features in the scholarly discourse about the Green Revolution are potentially relevant to the analysis of variety change in today's Pakistan. One is the role that transfer of seed and variety information from one farmer to another played in diffusion of the first generation of semi-dwarf wheat varieties and in their replacement by newer, improved releases (e.g., Hussain, Byerlee, and Heisey 1994). Although investment in public extension services was fundamental for delivering new seed and related information, widespread diffusion depended on informal, socially mediated exchange.

A second feature is the way that farm size shapes the process of seed-based technical change. A large body of theoretical and empirical research has explored the association of farm size with endowments of various types of capital (human, physical, social, political), and via these endowments, access to market infrastructure, including sources of information (e.g., Feder, Just, and Zilberman 1985; Feder and O'Mara 1982; Lipton and Longhurst 1989). Battese et al. (2014) also found that large-scale farmers are more productive and more efficient than small-scale farmers. A third feature was recognition of the importance to some farmers of variety attributes other than grain yield, such as fodder production (e.g., Renkow and Traxler 1994).

This analysis revisits these questions, with the goal of contributing to the design of programs to introduce high-zinc wheat varieties in Pakistan. Data were collected through interviews with 1,116 farmers during October–November 2011 in 23 districts of irrigated Punjab, representing 3 zones (rice-wheat, cotton-wheat, and mixed zones). Farmers are adopting new wheat varieties more rapidly in irrigated Punjab than in other wheat agro-ecologies of Pakistan, making it a "laboratory" for observing the dynamics of change in wheat variety.

Our conceptual approach is a trait-based model of seed (variety) choice derived from the theoretical framework of the agricultural household, which also recognizes the importance of variety information sources as farmers learn about variety attributes (Hintze, Renkow, and Sain 2003; Edmeades and Smale 2006). This conceptual approach is applied with a duration model that enables the explicit modeling of the timing of the variety change event as a function of variety traits, along with farmer and market characteristics. Duration analysis includes both time-varying and time-invariant parameters, in order to combine insights from cross-sectional and time-series data, and account for potential biases caused by unobserved lengths of time in "spells" or states, such as unemployment (Kiefer 1988). Widely applied by economists to a range of topics (Van den Berg 2001), duration analysis has been used relatively infrequently to model the adoption of agricultural innovations. Examples include studies of resource-conserving technologies by Fuglie and Kascak (2001); organic horticultural practices by Burton, Rigby, and Young (2003); adoption of cross-bred cows by Abdulai and Huffman (2005); and crop technology adoption in developing countries by Dadi, Burton, and Ozanne (2004) and Matuschke and Qaim (2008).

2. CONCEPTUAL FRAMEWORK

2.1 Hypotheses from Earlier Adoption Literature

The Green Revolution in the South Asia stimulated a vast literature about the adoption of agricultural innovations in developing economies, which built particularly on the seminal research conducted in the United States by Griliches (1960) and Rogers (1962). Exhaustive reviews of the first few decades of this literature were conducted by Feder, Just, and Zilberman (1985) and Feder and Umali (1993). Given the role of farmer knowledge and complementary inputs (fertilizer, adequate moisture) in the optimal performance of the first short-statured, high-yielding varieties, early empirical studies focused on the characteristics of farmers (education), access to credit, irrigation, and land.

A major theoretical paradigm of this period was farmer decision making under risk, depicting a farmer's land allocation between "modern" and "traditional" as a portfolio decision determined by risk aversion and the stochastic structure of relative yields (Just and Zilberman 1983). Safety-first and other motivations related to risk were also proposed (e.g., Roumasset, Boussard, and Singh 1979). Learning models were another hallmark of this early literature, in which farmers resolved uncertainty by accumulating knowledge about higher-yielding varieties through experimentation and experience, often portrayed as a Bayesian process (e.g., Hiebert 1974; O'Mara 1971; Feder and Slade 1984; Leathers and Smale 1991). Lindner, Fischer, and Pardey (1979) applied this framework in analyzing the time between adoptions of agricultural innovations.

Variety choice models of this type are less relevant in today's Pakistan because the adoption decision no longer involves the technology shift from a "traditional" (tall-statured, higher-yielding variety or heterogeneous, wheat landrace) to a "modern" (short-statured) fertilizer-responsive variety. Especially in the irrigated areas of Punjab, wheat farmers have experienced many generations of modern, higher-yielding varieties. Decisions in today's Punjab Province about replacing one modern wheat variety with another are based on whether the newly released variety performs better than the current modern variety, given a farmer's particular growing conditions and objectives. Farmers are more educated, have more access to public information, and do not need capital investments to shift from one high-yielding variety to another.

On the other hand, the decision to grow a newly released wheat variety is still a process that depends on how individual farmers seek and acquire information. Farmers "learn by doing," and they learn from others (Feder and Slade 1984; Foster and Rosensweig 1995). A major paradigm in recent adoption literature articulates the influence of social learning, social networks, and social capital in the choices made by individual farmers (Besley and Case 1997; Conley and Udry 2003; Munshi 2004; Bandiera and Rasul 2006). A principle in this literature is that costs, and access to information about a new technology, are related to capital endowments, such as farm size. In Punjab, even today, the survey data generated by this analysis confirm that public extension agents are more likely to work with larger-scale growers.

Further, each release of a new wheat variety has a unique configuration of traits. A segment of the variety choice literature demonstrated empirically that early utility-based models of decision making omitted variety traits, which are relevant factors in the decision making for semi-subsistence farmers (farmers who seek to satisfy their food needs through their own production and are subsistence-oriented, but also sell food crops for cash). Because of a focus on higher yields and yield stability, these models often ignored the role of traits in farmer decision making, such as grain and storage quality or fodder yield. Some researchers tested the importance of variety attributes, such as pest resistance and suitability for food preparation, by including them in econometric models alongside farmer characteristics and other determinants (e.g., Adesina and Zinnah 1993; Smale, Bellon, and Aguirre 2001). More complete models were then derived in the framework of the household farm by Hintze, Renkow, and Sain (2003) and Edmeades and Smale (2006). Examples of recent applications include Katungi et al. (2011), Otieno et al. (2011), and Timu et al. (2012).

These paradigms have influenced the conceptual framework of this analysis, summarized next. Specifically, we test the importance of variety traits in the decision to replace one higher-yielding wheat variety with another, explore the relationship between this decision and sources of information at the time of adoption, and test for differences in adoption parameters by farm size.

2.2 Conceptual Basis

This analysis views the choice of wheat varieties in any wheat-growing season from the general perspective of the well-known model of the agricultural household (Singh, Squire, and Strauss 1986). The agricultural household organizes family and hired labor in order to maximize utility over home-produced goods, purchased goods, and leisure time, given a farm production technology and an income constraint defined by net returns over tradable farm outputs, expenditures, and income from other sources or previous seasons. Profit maximization and the separation of consumption and production decisions constitute a special case, which may pertain for a very small minority of large-scale wheat farmers.

In the trait-based version of this model (Hintze, Renkow, and Sain 2003; Edmeades and Smale 2006), the agricultural household maximizes utility over the intrinsic attributes of the home-produced goods it consumes, a purchased good, and leisure time. In the case of this analysis, the home-produced good is wheat. Utility is maximized conditional on household characteristics that shape preferences (Φ_h) and market characteristics (Φ_m) that affect purchases. Variety choices are also constrained by production technology, which is defined by the traits that are genetically embedded in a variety and expressed when the seed is planted (**z**), and by the availability of seed (for variety ν_i). Expenditure constraints play an inconsequential role for wheat variety choice in Punjab, since seed costs are low, and the seed of higher-yielding varieties need not be replaced annually. Though expenditure constraints affect fertilizer and water use for growing wheat, fertilizer moisture response does not differ appreciably among current higher-yielding varieties, as would be the case between tall-statured and short-statured, or higher-yielding and landrace types. The production technology is conditioned on farm characteristics (Φ_f) and market characteristics. The variety supply ***V*** that is available in the farmer's location constrains choice, and reflects both the potential for farmer-to-farmer transfer and the delivery of wheat seed via formal channels (Edmeades and Smale 2006).

The attributes of new releases are not known to farmers before the variety is grown or observed in the field. Consistent with the social learning literature, and with both historical and current evidence for this region and crop, we hypothesize that farmers learn about variety traits from others, and particularly about new varieties, by seeking information. The local supply of varieties (***V***), household, market, and farm characteristics that influence the cost of obtaining information, and opportunities for social learning (Ω) affect the farmer's knowledge about wheat varieties.

A farmer *i* decides to replace an old with a newer, higher-yielding variety of wheat if the overall utility of adopting, U_{i1}, is larger than the utility of not adopting U_{i0}. In other words, $(U_{i1} - U_{i0}) > 0$. We can define an unobservable $\nu_i^*=(U_{i1} - U_{i0})$, and express it as a function of observable elements in a latent variable model

$$\nu_i^*=\omega_i\gamma+\mu_i \qquad (1)$$

In equation 1, ω summarizes the vectors of explanatory factors described above (**z**, ***V***, Φ, Ω), conditional on variety information. The variable ν_i^* refers to a binary choice that is observed at time ***t***:

$$\nu_i^*(t) = \begin{cases} 1 & \text{if } \nu_i^*(t) > 0,\ \omega_i\gamma \geq -\mu_i \\ 0 & \text{if } \nu_i^*(t) < 0,\ \omega_i\gamma < -\mu_i \end{cases} \qquad (2)$$

γ is a vector of parameters to be estimated, and μ_i is the error term, which is assumed to be normally distributed.

3. EMPIRICAL STRATEGY

3.1 Duration Model

Since the 1980s, duration models have been applied to analyze the timing of economic events in the fields of labor economics and migration, human and business life cycles, stock market and firm investment behavior, and other topics. Their widespread use reflects the growing importance placed on the dynamics of decision making, and the role of information (Van den Berg 2001). In his review of duration analysis as applied to the study of unemployment, Kiefer (1988) noted that "short spells will be underrepresented" in a current sample of employed and unemployed, generating "length-biased sampling." Similarly, data recording variety use in a single period cannot adequately capture the timing of the decision to change from one state (variety) to another, or the duration of variety use once adopted.

Kiefer's (1988) perspective, which we assume here, is that econometric methods based on hazard functions provide a "natural" approach for analyzing data that can be modeled sequentially. He modeled the duration time (*T*) as a non-negative, continuous random variable with cumulative distribution function

$$F(t) = \int_0^t f(t)\,dt = \Pr(T < t). \qquad (3)$$

The survivor function, which expresses the probability that duration time t is greater than some value of t, is defined as $S(t) = 1-F(t)=\Pr(T > t)$. Duration analysis utilizes the related hazard function, $h(t)=f(t)/S(t)$. According to Kiefer (1988:11), $h(t)$ is "the rate at which spells will be completed at duration *t*, given that they last until *t*"—or more precisely,

$$h(t) = \lim h \rightarrow 0 \Pr(t \leq T < t+h | T \geq t)/h. \qquad (4)$$

Conveniently, the hazard rate is equivalent to the inverse Mills' ratio of the sample selection literature (Kiefer 1988:11).

A common specification of hazard function is the proportional hazard model, in which the function *h* depends on a vector of explanatory variables **x** with estimable coefficients β. The baseline h_0 is factored out, and corresponds to the value of the function at 1 (Kiefer 1988):

$$h(t, x, \beta, h_0) = \varphi(x,\beta)\, h_0(t) \qquad (5)$$

The coefficients estimated with a proportional hazard model can be interpreted as partial derivatives, as in a linear regression model. Van den Berg (2001) refers to this approach as reduced form, expressing an exit rate to a destination state as a function of observed and unobserved explanatory variables, and the elapsed time in the current state. The proportional hazard model has the advantage that it imposes no parametric form on the baseline hazard and allows the hazard to shift, in steps, over the duration (Burton, Rigby, and Young 2003).

The function *f(t)* is often specified as exponential or Weibull in form. The Weibull has the form $f(t)= \gamma \alpha t^{\alpha-1}$, with parameter γ. The exponential distribution is a special case of the Weibull, when $\alpha = 1$. The exponential distribution is characterized by a constant hazard function, which implies that the passage of time does not affect the hazard rate. The Weibull distribution is characterized by either an increasing or a decreasing hazard, including the exponential as a special case when the rate is constant. The suitability of the Weibull as compared with the exponential form can be tested statistically. Parametric estimation is accomplished by maximizing the likelihood function.

Generally speaking, duration analysis enables identification of the factors that have the potential to change the estimated probability that the state occupied by an individual will end in the next short time interval. More specifically, duration analysis can be applied to predict the time (*t*) to adoption of an agricultural innovation. For example, Abdulai and Huffman (2005) applied an investment timing model with perfect information as the conceptual basis for a duration model they applied to predict the time until adoption of cross-bred cows in Tanzania.

In their model, farm-level heterogeneity in the time to adoption then depended on "rank, stock, and order" effects. Rank referred to differences in profitability among farms. Stock effects described the influence of the cumulative adoption rates in a location on farm profits. Order effects pertained to the farm's position in the succession of adopters (early or late).

Other examples include Burton, Rigby, and Young (2003), who applied duration analysis to model the adoption of organic horticultural techniques in the United Kingdom, and Dadi, Burton, and Ozanne (2004), who modeled the time to adoption of fertilizer and herbicide on tef in the Ethiopian Highlands. Reflecting Kiefer's (1988) point concerning "length bias," Burton, Rigby, and Young (2003) present duration analysis as a means of including both adoption and diffusion components of agricultural innovation. Adoption studies, which are typically based on a single cross-section of data, fail to allow for the timing of the adoption event, but account for farmer heterogeneity in the decision. On the other hand, diffusion studies that model cumulative adoption in the aggregate ignore why some farmers adopt earlier than others, and household-specific determinants of adoption.

Duration analysis can also be used to predict the time lag from the release of a newer, higher-yielding variety and its first year of use by a farm household. Recently, Matuschke and Qaim (2008) applied a duration model to test the effects of privatization of the seed industry on the adoption of pearl millet hybrids in India. Our application is closest to that of Matuschke and Qaim (2008), but differs in that we are examining the replacement of one higher-yielding variety with another, rather than the adoption of a hybrid for the first time. Our perspective differs substantially from those of Abdulai and Huffman (2005), Burton, Rigby, and Young (2003) and Dadi, Burton, and Ozanne (2004), in that the replacement of one higher-yielding wheat variety by another does not entail a major investment decision.

Where Matuschke and Qaim included social activity as one of their regressors, our focus is on the role of information sources. Burton, Rigby, and Young (2003) and Dadi, Burton, and Ozanne (2004) also view information as a major factor in the adoption process for organic practices, including both public sources of information and social network sources. Dadi, Burton, and Ozanne (2004) and Matuschke and Qaim (2008) differentiate between time-invariant and time-varying factors that influence the length of the adoption lag.

In this analysis, the hazard function represents the probability that the farmer in the irrigated areas of Punjab, Pakistan, replaces the currently grown higher-yielding wheat variety with a new higher-yielding variety at time t, given that he continues to grow the current variety before time t. Variables are defined in greater detail below, after a summary of the data source.

3.2 Data

The data are drawn from a survey among wheat farmers conducted during October–November 2011 in Punjab, the largest province of Pakistan. Punjab includes 76 percent of the country's wheat area (GOP, 2011b). The sample covers 1,116 wheat farmers in 93 villages, located in 23 districts of three agro-climatic zones (cotton-wheat, rice-wheat, and mixed zones).

A stratified two-stage (unequal size) cluster design was used to draw the sample. The three wheat production zones represented the strata, or first-stage sampling unit. The second-stage sample unit was the *mauza* (known as a revenue village, with known population sizes and recognized as an administrative unit). The *mauzas* were allocated proportionately across agro-climatic zones (rice-wheat, mixed, and cotton-wheat), based on the share of total wheat land area. Proportional allocation ensures that the sampling fraction in each stratum is equivalent to the sampling fraction of the population. A systematic probability-proportionate-to-estimated-size approach was used for the selection of *mauzas* (clusters) within each agro-climatic zone (stratum), using secondary data on the population size (total number of households) of each *mauza*. In total, 93 *mauzas* from 23 districts in three zones were selected from the irrigated, high-intensity wheat-farming areas of Punjab.

Following the selection of *mauzas* in the first stage, wheat-farming households were selected at random within each village. From previous surveys and research conducted in Pakistan (GOP 1991), the non-response rate is estimated at 33 percent for interviewing conducted at the second-stage selection. This rate was adapted in this study and prescribes 6 spare households to be selected within each *mauza*. A total of 18 households were selected in each village, of which 12 were interviewed. The final sample consisted of 1,116 farmers, of whom 41 percent were selected from the cotton-wheat zone, 32 percent from the rice-wheat zone, and 27 percent from the mixed zone.

Respondents were the household members who were responsible for wheat production decision making during the growing season. Additional details on the survey and instrument are found in Nazli et al. (2012).

3.3 Variables

Definitions of the dependent and explanatory variables, means and standard deviations, are shown in Table 1. Following Dadi, Burton, and Ozanne (2004), the operational variables used to measure ($\mathbf{z}, \boldsymbol{V}, \Phi, \Omega$) are grouped as time-invariant and time-variant. As is common in this limited literature, many of our empirical variables are binary, potentially generating a step or shift in the hazard function.

Time to Variety Change

The dependent variable used in the analysis is the time to first use of a variety grown by the farmer during the survey year, measured as the difference between the year of adoption and the year of release. The average time to variety change in irrigated areas of Punjab among farmers surveyed in 2011 was 6.5 years, ranging from 1 to 30 years.

A histogram of the dependent variable suggests a bimodal distribution, reflecting the two most popular varieties grown by farmers surveyed: Inqilab, which was released in 1991, and Seher, which was released in 2006 (Figure 1). Inqilab was grown on more than 70 percent of the wheat area for 13 years, and on nearly half of Punjab in 2007/08. However, Seher replaced Inqilab and became the most popular variety in 2010, occupying 42 percent of the wheat area in Punjab (Government of Punjab, 2011).

We treated the year of release of these two varieties as "regime changes" in terms of the rate of cumulative use (adoption), introducing dummy variables as time-varying covariates. Each dummy takes a value of one if the release year of a variety is more recent than 1991; otherwise, its value is zero.

Household Characteristics

Household characteristics (Φ_h) include the age of the household member who is responsible for wheat production decisions at the time of variety change (a time-varying covariate), and endowments of human and financial capital. While younger farmers are often thought to be less risk averse and, therefore, more willing to test a new technique or variety, some studies have shown that older farmers are likely to adopt a new technology because they are more experienced (Lapar and Pandey 1999; Abdulai and Huffman 2005). Human capital is represented by the quality and quantity of labor. Quality of labor is measured in terms of the respondent's literacy. The active labor supply in the household, or quantity of labor, is measured as the number of people between 15 and 65 years of age. Ownership of livestock with large relative economic value (cattle and buffalo) is used as the indicator of the asset base of the household, but also as an indicator of a demand for wheat straw. A priori, we expect a shorter time to replacement of the current variety with a newer, higher-yielding variety among farmers with greater capital endowments. The significance of wheat fodder demand in time to variety replacement would depend on the variety.

Farm Characteristics

For farm characteristics, this analysis uses both whether the farmer is a tenant (renting land or sharecropping) and dummy variables for the size category of the farm (Φ_f). Following the standard classification used in Pakistan, we group farmers into three categories based on cultivated land: marginal (cultivate up to 5 acres), small scale (cultivate up to 12.5 acres but more than 5 acres), and medium–large scale (cultivate more than 12.5 acres). Most wheat farmers (71 percent) belong to the marginal and small-scale categories.

We hypothesize that large-scale farmers replace existing wheat varieties with new, higher-yielding varieties faster than small-scale and marginal farmers because they have better access to information and seed sources. A fundamental feature of Green Revolution technology was that it was largely considered to be scale-neutral (Hazell 2010), although Feder and Slade (1984) argued that scale bias was introduced via access to water and fertilizer. During the post-Green Revolution period, differences in fertilizer or moisture response among higher-yielding varieties are not likely to be as appreciable as between taller-statured and semi-dwarf wheat varieties, and farmers have already made related investments in irrigation. In 1990, Heisey concluded that in the presence of other variables, farm size usually became a less significant determinant of variety change in areas where new varieties had already been widely adopted and smaller farmers had become aware of them.

Market characteristics (Φ_m) are represented by the distance (kilometers) to input dealer and the lagged wheat price. The greater the distance to the input dealer, the slower is the expected time to adoption of new wheat varieties. A negative sign is expected for the distance variable, as was found by Matuschke and Qaim (2008).

The survey data show that a majority of farmers (78 percent) acquired the seed of the varieties they planted from their own previous harvest, or at some time in the preceding year from other farmers. Wheat seed prices were reported for less than one-third of farmers. Also, the relevant seed price for our model would be the price at the time of variety change, which was not recorded in the survey. As a proxy, time series data were used on the average wheat price in major cities of irrigated districts of Punjab in the year of the variety's first use, lagged by one year. Wheat prices varied little across cities (GOP 2011b). We hypothesize a negative sign on the coefficient of this variable.

We measure the supply of wheat varieties *V* as the total count of different wheat varieties grown in the *mauza*. Empirical research and social learning theory suggest that the higher the number of varieties grown, the more likely an individual farmer will be to test a new variety (Besley and Case 1997; Foster and Rosensweig 1995). However, the new variety may not be the major variety, which we have measured here. A greater number of varieties grown in a *mauza* may also indicate a wider range of production constraints or consumption preferences in that location, and a slower time to variety change. Thus, this analysis has no hypothesis concerning the direction of effect.

The social learning variables (Ω) are grouped into formal, informal, and social categories. Each represents the source of information about the current major variety at the time of its first use. Formal sources include extension services, print and electronic media, and the Internet. Village input dealers, large landlords, and shopkeepers are grouped as informal sources. Friends, neighbors and relatives are classified as "social" sources. These categories follow previous empirical research conducted in Pakistan (Tetlay, Heisey, and Ahmad 1987; Ahmad et al. 1991; Khan, Morgan, and Sofranko 1990; Muhammad and Garforth, 1999; Abbas et al. 2003; Taj et al. 2009). Though broad, this categorization underscores hypothesized differences in costs of information acquisition. A priori, we cannot predict the sign of the relationship between sources of information and speed of variety change.

Variety traits are also considered in the variety change decision. We began by developing a list of key traits with wheat scientists and experts in Pakistan, finalizing the list following the pre-test of the survey instrument. Farmers were asked to report the degree of importance of various traits in their choice of a wheat variety on a five-point Likert scale (1 = unimportant, 2 = of little importance, 3 = moderately important, 4 = important, and 5 = very important). The most important production traits were grain yield and grain size; and the most important consumption trait was the taste of chapati[1] , which was cited as important or very important by more than 90 percent of farmers. Other important traits, identified by more than 80 percent of farmers, are panicle length, price, chapati color, and nutritional value. Labor requirement appeared to be the least important trait (Nazli et al. 2012).

Rather than including all traits individually in the regression, principal components with varimax rotation were used to reduce the number of variables based on correlation structure, selecting factors with eigenvalues greater than 1 in magnitude. The relative sizes of the coefficients that contribute to variation in the factors led to naming factor 1 as "input traits," factor 2 as "production traits," and factor 3 as "consumption traits" (Table 1). First, farmers appear to differentiate agronomic and consumption traits. In factor 1, traits of interest are primarily those related to profitability, including the amounts of fertilizer and water needed, and labor requirements, followed by pest and rust resistance. Factor 2 is strongly affected by grain yield and by grain and panicle length. The variables with the largest coefficients in factor 3 are chapati quality (taste, color, freshness) and nutritional value. Thus, the correlation structure in the data supports the underlying motivation of the trait-based model.

Finally, the dummy variables for the agro-climatic zones (rice-wheat, cotton-wheat, and mixed zone) are used to control for the regional effects.

4. RESULTS AND DISCUSSION

This section presents (1) the Kaplan-Meier curve, which provides guidance concerning the selection of the form of the hazard function (Weibull v. exponential); (2) test results comparing models estimated using Weibull with exponential forms; (3) test results comparing the pooled model, which does not allow for distinguishing duration parameters by farm size with the separate models, and (4) regression results for the separate models.

4.1 Kaplan-Meier Curve

Before estimating the duration model, the Kaplan-Meier curve is often estimated to examine baseline survival times, independent of explanatory factors. The Kaplan-Meier curve represents the proportion of the study population still surviving at each successive point in time. The approach is nonparametric, and thus requires no assumptions regarding the underlying distribution of survival times (lags in variety change). However, the shape of the curve provides some evidence concerning the appropriateness of the distribution assumed in this econometric analysis. The period of observation is divided into a series of intervals, each containing one or more variety change events at its beginning.

The Kaplan-Meier estimate of the time-to-variety change function for the full sample is shown in Figure 2. Here, the curve portrays the proportion of farmers who had not yet adopted the new, higher-yielding variety that was their major wheat variety in the survey year (2011), in each year from the earliest release represented in the data (1979). The function is valued "1" when time equals "0." This means that, initially, all farmers are considered to be non-adopters. The value of the function falls sharply in the first 6 years, indicating that most varieties are adopted within this time period. Between 6 and 20 years, the function declines at a slower rate, and is almost flat between 20 and 30 years, for a very small proportion of varieties.

One point of reference for the length of time lag to variety change lag is the analysis by Heisey and Brennan (1991). The authors estimated that during the post-Green Revolution period, when yield gains attained in wheat through genetic improvement fluctuated around a trend line indicating 0.75 percent per year, it paid farmers to change improved varieties every 4 years. Differences in micro-environments and biotic pressures, such as rust diseases, influence the optimal rate of change. Figure 2 suggests that a substantial proportion of wheat farmers in the irrigated areas of Punjab may be meeting this mark, although wheat yield gains have also likely changed since that time period.

A priori, as discussed above, there are strong reasons to expect that variety change parameters differ by farm size category. Figure 3 depicts the Kaplan-Meier curves differentiated by farm size group. Differences in time-to-variety change are most evident between the medium- and large-scale group and the other two groups (marginal and small-scale groups), and particularly in the range between 6 and 20 years. The step function is also slightly steeper for the medium–large-scale farmers during the first 6 years.

4.2 Distributional Form

The Kaplan-Meier curve shows that survival is monotonically decreasing and hazard is increasing over time. Therefore, the data support the application of a duration model that assumes a Weibull distributional form. Another way to compare and select the best-fit model is to compare the Akaike information criterion (AIC) for different

[1] Unleavened flatbread that is commonly consumed in Pakistan.

distributions. The AIC is defined as [–2lnL + 2(k+c)], where k is the number of independent variables in the model, and c is the number of model-specific distribution parameters.

Table 3 reports the estimated coefficients and diagnostic test for duration models that assume the Weibull and the exponential distributions. Regression results are similar between the two models, although the significance of several individual coefficients and overall tests of significance favor the assumption of the Weibull distributional form. The AIC associated with the Weibull distribution is lower than that of the model estimated with the exponential distribution.

4.3 Farm Size

Next, we applied the likelihood-ratio test, to compare the fit of regression that pools the sample across farm sizes with that of the regressions estimated separately for each farm size category. The null hypothesis, or the restricted regression, is that parameters are constant across farm sizes. Comparison of the values of the likelihood functions for the restricted regression to the sum of values for all three separate regressions generates a Chi-squared statistic of 63.28 (dof = 51), which is greater than the critical value at the 10 percent level of significance. While this level of statistical significance is weak, we also have an analytical interest in distinguishing the effects of individual factors, such as information sources, by farm size. Thus, we reject the restricted model in favor of the unrestricted model.

The results of maximum-likelihood estimation of duration models with Weibull distributions across three farm size groups are presented in Table 4. An important diagnostic test is the value of the Weibull parameter [ln (p)]. The value of ln(p) of greater than 1 in all three models indicates that the hazard (survival, or time to variety change) is increasing over time. At the 95 percent confidence interval, the null hypothesis that [ln (p) =1] is rejected, because, as noted above, it would favor an exponential distribution.

Table 4 reports hazard ratios, with robust standard errors in parentheses. A hazard ratio greater than 1 denotes that the variable shortens the time to variety change, while a hazard ratio less than 1 lengthens the time. Time-varying covariates representing major technological and diffusion shifts in wheat varieties (releases of Inqilab and Seher) are highly significant and large in magnitude for all groups of farmers. As hypothesized, higher wheat (seed) prices lengthen the time to variety change, for all farm sizes.

Findings confirm that hazard functions differ across farm size groups, providing additional insights on heterogeneity among farmers in the irrigated areas of Punjab. Statistically significant covariates and the magnitudes of the hazard ratios are differentiated by farm size category.

With respect to household characteristics, literacy plays a significant role in the time to variety change for small, medium, and large farmers, but not among marginal farmers. Family labor supply appears to matter for the rate of variety change among small-scale farmers only, reducing the time lag. This finding may reflect the fact that these farmers face labor constraints in wheat production. In addition, the age at the time of initial use reduces the time to variety change among marginal farmers, increases it among medium–large-scale farmers, and has no discernible effect for the small-scale group. It may be that older farmers in the marginal group have gained experience and are better connected to seed and information sources, while younger farmers in the medium–large-scale group are more willing to try new varieties.

Distance to input dealers is also significant only for smaller-scale farmers, indicating that it slows variety change. The number of varieties in the *mauza* is statistically insignificant when farmers are disaggregated by farm size, though the magnitude of the hazard ratio (less than 1) is consistent with that of the pooled regression. Thus, variety richness (diversity across a spatial scale) at any point in time may have a dampening effect on variety change (diversity over time).

Unexpectedly, tenure has a strong effect only on medium–larger-scale farmers. Capacity to rent land for cultivating wheat from others may enable this group of farmers to experiment with new wheat varieties sooner.

When disaggregated by farm size group, relative to social sources of information, formal sources at the time of first use have strongly significant, positive association with the speed of variety change among medium–large- and small-scale farmers in the irrigated areas of Punjab. The magnitudes of these effects are substantial. Among marginal farmers, neither formal nor informal categories have a significant effect on the time to variety change compared with social sources of variety information. The separate effects of informal sources of information are not statistically discernible.

The effects of trait preferences are heterogeneous across farm size categories. An interest in input traits extends the time to variety change among marginal farmers, but reduces it among small-scale farmers and does not have any significant impact on medium–large-scale farmers. Another surprising result is the insignificant coefficient of production traits (which measures yield) in the case of smaller-scale and medium–larger-scale farmers. Clearly, access to water and fertilizer, profitability, and resistance to biotic stresses are greater constraints for smaller-scale than larger-scale farmers. This is not surprising, given the environmental and economic challenges faced by farmers in these high-potential production zones.

Grain yield appears to be of paramount importance to marginal farmers, speeding variety change. This finding indicates that the marginal farmers prefer higher-yielding varieties, so that they can increase their total production of wheat on the limited land that they cultivate (less than 5 acres). Most of these farmers produce less wheat than they need to meet their consumption needs (Nazli et al. 2012). An increase in production can enable them to produce surplus wheat.

Among small-scale farmers only, consumption traits also speed variety change. On the other hand, none of the trait factors matters in the hazard function estimated for medium–large-scale wheat farmers. Overall, these results are consistent with the decision making framework of the household farm, which includes profit maximization as a special case. Medium–larger-scale farmers are more commercially oriented, selling most of their harvest.

The only significant difference across agro-climatic zones is observed among medium–large-scale farmers, where location in the mixed farming zone strongly slows variety change relative to other zones.

5. CONCLUSIONS

To design a strategy to promote high-zinc wheat varieties in Pakistan, policy makers need to understand why some varieties become more popular than others, and how the processes that influence popularity differ by target group. Referring to historical literature about the Green Revolution and findings from a recent baseline study in the irrigated areas of Punjab, this analysis highlights recurring themes concerning the importance of farmer-to-farmer exchange of information alongside formal delivery mechanisms, the significance of traits other than yield in a heterogeneous farm population that both consumes and sells wheat, and farm size structure.

Based on these themes, we propose a trait-based conceptual approach for analyzing variety choice that incorporates the roles of information source and social learning. In its empirical application, this analysis merges elements of adoption and diffusion models in a duration analysis. In today's Pakistan, time to adoption refers to the number of years from the release of a modern variety to its use by a farmer. Farmers in Pakistan have grown modern varieties for decades, and adoption implies the replacement of one modern variety with another.

As was the case in the earlier phases of the Green and post-Green Revolution, we find ample support for the argument that overall, wheat growers in the irrigated areas of Punjab are innovative, rapid adopters, given that they have the seed and the information. The data also confirm that parameters that influence the time to variety change are heterogeneous among farm size groups. Some of this heterogeneity conforms to our expectations, given the underlying conceptual framework of the household farm.

For example, distance to the nearest input dealer and availability of labor constrain variety change among small-scale farmers (who tend to both sell and purchase), but not other groups. Marginal farmers are less likely to sell, and larger farmers are more likely to sell and not purchase. Concern for input traits (water and fertilizer, profitability, and resistance to biotic pressures) extends the time to variety change among marginal wheat growers, but reduces it among small-scale growers. A subsistence motivation may drive the focus of marginal farmers on grain yield above other variety traits, strongly reducing time to variety change. Smaller-scale farmers also value consumption traits, and these also drive their variety change decisions.

Relative to strictly "social" (friends, relatives) and informal (input dealers, large landowners) sources of information, formal (agents, media) sources of information significantly affect rates of variety change for both small-scale and medium–larger-scale farmers, but not marginal farmers. The role of literacy follows this pattern, while among marginal farmers, older age at first use positively influenced variety change. By contrast, younger age has a positive influence among medium–large-scale farmers.

The Kaplan-Meier curve and the large magnitudes of the effects of shift variables indicating major breeding advances (Inqilab and Seher) attest to the relatively rapid rates of variety change among a substantial proportion of farmers in the irrigated areas of Punjab in 2011. For roughly half of farmers surveyed, time to variety change compares favorably with the optimal rates recommended in 1991 by Heisey and Brennan (4 years), although further research would be needed to produce estimates fully comparable with those calculated for that time period.

That said, policy attention is needed to meet the information needs of particular farmers, as evidenced by the persistent importance of such variables as literacy, labour supply, and distance to input dealers. Furthermore, it is likely that the results of this analysis would look very different had they been estimated for rainfed wheat-growing environments of Pakistan.

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Table 1: Factor score coefficients, based on rotated factor matrix

Variable	Factor 1	Factor 2	Factor 3
	Input and market traits	Production traits	Consumption traits
Maturity	0.01382	0.04583	0.11959
Grain yield	−0.01697	0.22625	−0.05956
Grain size	−0.08036	0.30757	0.00054
Panicle	−0.06177	0.28467	0.00587
Dry fodder yield	0.10674	0.12862	−0.07714
Insect resistance	0.21045	0.09623	−0.12395
Rust resistance	0.2043	0.10097	−0.11166
Lodging resistance	0.16892	0.12082	−0.09306
Water requirement	0.26809	−0.12373	0.02573
Fertilizer requirement	0.2467	−0.14843	0.05673
Labor requirement	0.24295	−0.09972	−0.0266
Good market price	−0.04547	0.16306	0.03956
Reliable demand	−0.06475	0.20498	0.03087
Chapati taste	−0.04831	0.00852	0.29594
Chapati color	−0.12113	0.03255	0.33488
Chapati freshness*	−0.01822	-0.07172	0.30822
Nutritional value	0.03689	-0.12915	0.29194
Eigenvalue	4.88	2.08	1.88

Source: Authors. (*) Chapati can be kept overnight. N =1,116.

Table 2: Variable definitions and descriptive statistics

Variable	Definition	Mean	Std. Dev.
Dependent variable			
Time to variety change	Number of years from date of release to date of first use of the major variety grown in survey year	6.48	5.46
Independent variables			
Time-invariant covariates			
Age at first use	Age of respondent in years at the time of variety change	46. 61	12.94
Literacy	1 = if main respondent is literate	0.64	0.48
Labor	Number of working-age members (age 15–65 years) per acre	1.13	2.20
Land rented-in	1= household rented-in or sharecropped-in some land for cultivation	0.29	0.45
Own livestock	Ownership of cattle, buffalo, cow = 1; 0 otherwise	0.91	0.28
Distance	Distance to nearest input dealer (km)	8.76	8.20
Formal information	1 = source of information at time of variety change was extension agent or media; 0 otherwise	0.17	0.37
Informal information	1 = source of information at time of variety change was input dealer, shopkeeper, or landlord; 0 otherwise	0.13	0.34
Social information	1 = source of information at time of variety change was a friend, relative, or neighbor; 0 otherwise	0.70	0.46
Variety supply	Number of wheat varieties grown in village	17.08	3.47
Marginal farm	1 = if farmer's cultivated land is less than 5 acres; 0 otherwise	0.28	0.45
Small-scale farm	1 = if farmer's cultivated land is between 5 and 12.5 acres; 0 otherwise	0.35	0.48
Medium–large farm	1 = if farmer's cultivated land is greater than 12.5 acres; 0 otherwise	0.37	0.48
Rice-wheat zone	1 = farm is in rice-wheat zone; 0 otherwise	0.31	0.46
Cotton-wheat zone	1 = farm is in cotton-wheat zone; 0 otherwise	0.43	0.50
Mixed zone	1 =f arm is in mixed (farming system) zone; 0 otherwise	0.26	0.44
Time-varying covariates			
Wheat price	1 year lagged average price of wheat at the time of variety change in major cities, (Rs/40 kg)	527.15	188.86
Release of Inqilab	1 = year of variety release is greater than 1991; zero otherwise	0.85	0.36
Release of Seher	1 = year of variety release is greater than 2006; zero otherwise	0.09	0.29

Source: Authors.

Table 3: Coefficient estimates of duration models assuming Weibull and exponential distributions

Variable	Weibull	Exponential
Age at variety change	–0.0018	–0.0001
	(0.0027)	(0.0013)
Literacy	0.2021***	0.1232***
	(0.0776)	(0.0372)
Labor	0.0161**	0.0060
	(0.0082)	(0.0040)
Own livestock	0.0921	0.0284
	(0.1574)	(0.0658)
Distance	–0.0073	–0.0035
	(0.0054)	(0.0024)
Wheat price	–0.0009***	–0.0007***
	(0.0002)	(0.0001)
Land rented	0.2064**	0.0911**
	(0.0824)	(0.0365)
Variety supply	–0.0244*	–0.0097
	(0.0145)	(0.0064)
Release of Inqilab	2.0714***	1.2535***
	(0.0990)	(0.0398)
Release of Seher	1.9898***	0.9930***
	(0.0899)	(0.0454)
Input traits	0.0279	0.0177
	(0.0369)	(0.0186)
Production traits	0.0644*	0.0349**
	(0.0345)	(0.0173)
Consumption traits	0.1031**	0.0448
	(0.0511)	(0.0294)
Formal sources of information	0.1556*	0.0539
	(0.0916)	(0.0413)
Informal sources of information	0.0520	0.0411
	(0.1250)	(0.0569)
Small scale	–0.0072	–0.0052
	(0.0947)	(0.0435)
Medium–large scale	–0.1280	–0.0708*
	(0.0852)	(0.0402)
Cotton-wheat zone	0.0417	0.0468
	(0.0999)	(0.0467)
Mixed zone	–0.2642**	–0.1216*
	(0.1297)	(0.0673)
Constant	–4.5054***	–2.3742***
	(0.3609)	(0.1537)
Model diagnostics		
AIC	2,474.96	3,239.42
BIC	2,585.28	3,344.48

Source: Authors. Sample size =1,143

Table 4: Duration models by farm size group

Variable	Hazard ratio (robust standard error)		
	Marginal farmers	Small farmers	Medium/large farmers
Age at variety change	1.0096*	0.9986	0.9902**
	(0.0054)	(0.0041)	(0.0040)
Literacy	1.2024	1.3040**	1.2172**
	(0.1615)	(0.1665)	(0.1202)
Labor	1.0078	1.0495***	1.0072
	(0.0258)	(0.0147)	(0.0189)
Own livestock	0.9087	1.4939	1.1717
	(0.1440)	(0.5367)	(0.2398)
Distance	0.9970	0.9916*	0.9894
	(0.0091)	(0.0048)	(0.0073)
Wheat price	0.9993*	0.9988***	0.9992***
	(0.0004)	(0.0003)	(0.0003)
Land rented	1.1476	1.2116	1.3735***
	(0.1507)	(0.1600)	(0.1458)
Variety supply	0.9859	0.9786	0.9762
	(0.0185)	(0.0169)	(0.0175)
Release of Inqilab	9.0760***	9.2782***	7.3536***
	(1.5253)	(1.4955)	(1.0153)
Release of Seher	5.6656***	8.3020***	7.5836***
	(0.9237)	(1.3115)	(0.9471)
Input traits	0.8991**	1.1955***	1.0490
	(0.0452)	(0.0772)	(0.0526)
Production traits	1.1720**	0.9931	1.0911
	(0.0723)	(0.0581)	(0.0608)
Consumption traits	1.0765	1.1943***	1.0068
	(0.0815)	(0.0748)	(0.0414)
Formal information	0.8725	1.3881**	1.2483*
	(0.1868)	(0.1940)	(0.1451)
Informal source	0.8034	1.0987	1.2418
	(0.1998)	(0.2003)	(0.1651)
Cotton-wheat zone	1.0416	1.1926	0.9522
	(0.1514)	(0.1720)	(0.1238)
Mixed zone	0.8069	0.7763	0.6982**
	(0.1547)	(0.1467)	(0.1144)
ln(p)	1.9028***	1.9575***	1.8848***
	(0.0716)	(0.0740)	(0.0665)
Log likelihood	–338.09	–402.51	–446.52
Observations	405	488	520

Weibull model. *** p<0.01, ** p<0.05, * p<0.1

Source: Authors.

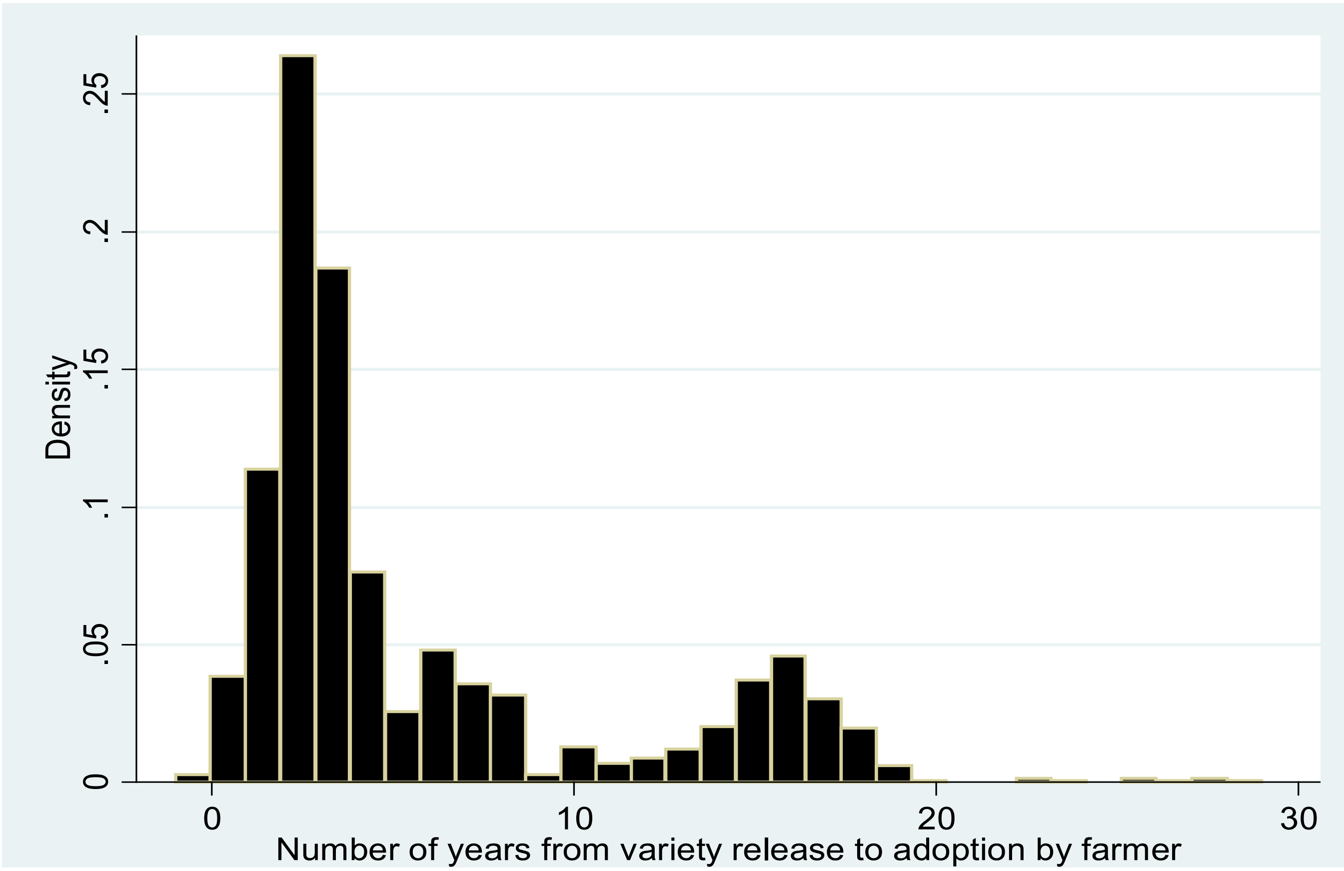

Figure 1. Time to variety change of major wheat variety grown in survey year

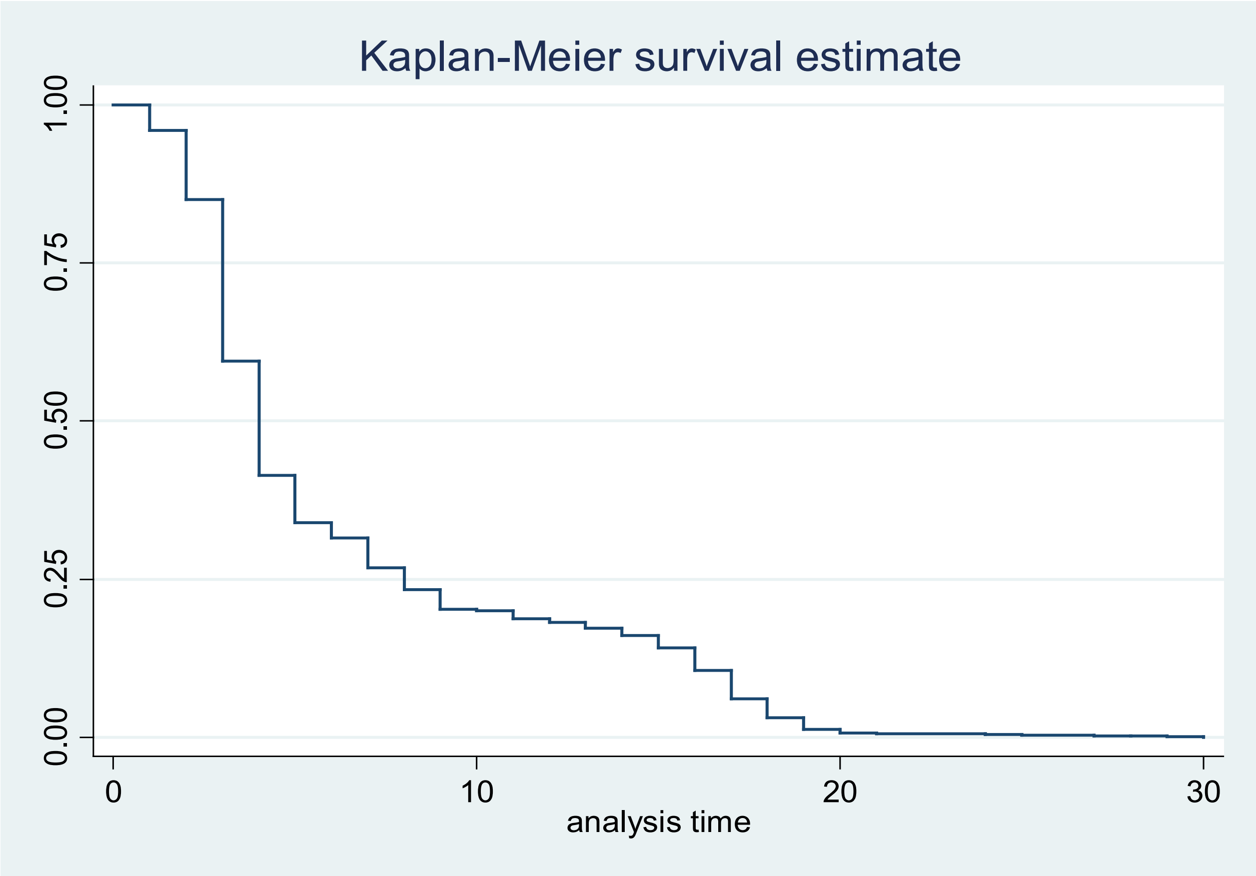

Figure 2. Baseline time-to-variety change function (Kaplan-Meier)

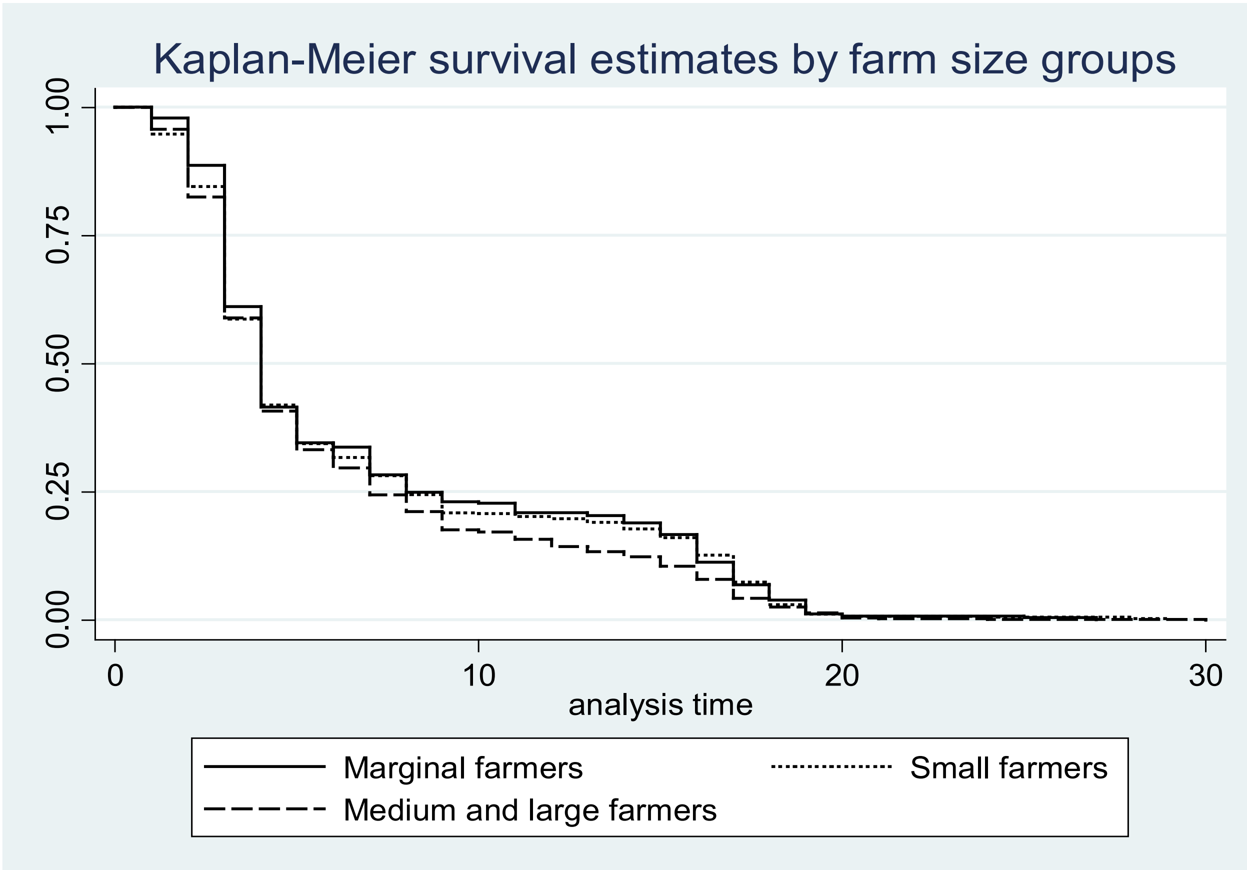

Figure 3. Baseline time-to-variety change function (Kaplan-Meier) by farm size groups