Estimating the Contribution of New Seed Cultivars to Crop Yield Increases: Method and Application

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Abstract:

Assessing the contribution made by new seed cultivars to nationwide yield increases is critically important to planning for future yields. This study focuses on a method that enables the contribution of seed cultivars to nationwide yield increases to be estimated by means of dividing the study period into several diffusion periods characterised by the replacement of major seed cultivars and by specifying a yield response model that incorporates a series of dummy variables to capture net increases due to new cultivar diffusion in each such period. Using this method, the contributions over the base period were estimated to be 1303.8 kg/ha, 523.0 kg/ha, 1179.5 kg/ha, 316.9 kg/ha, 196.8 kg/ha, and 414.2 kg/ha for rice, wheat, corn, soybeans, cotton, and rapeseed, respectively, accounting for 47.9%, 33.3%, 47.6%, 41.4%, 34.0%, and 46.5% of total yield increases, respectively. This method has several advantages, being concise, easy to use, and flexible; further, it can distinguish historical contributions of seed and can therefore be used for tracking assessments. It is thus likely to be applicable in several practical ways to measure the developmental status of both seed breeding technologies and agricultural techniques.

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Keywords: crop, yield increase; seed cultivar; contribution, estimation method

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1. Introduction

Seed is the main input for crop production, and seed technology is therefore the most important aspect of agricultural technology in terms of the sustainable development of agriculture [1]. Past increases in crop yield have largely resulted from increases in input factors, but once these have been maximized, as under current agricultural conditions, further large increases from agricultural inputs seem unlikely. Even though further improvement in input use efficiency is still a challenging issue via crop management practices [2], future crop yield gains are therefore likely to rely more heavily on the adoption of new and improved cultivars [3]. It is therefore important to be able to scientifically estimate the contribution of novel seed cultivars to crop yield increases in order to incorporate this information into agricultural and technological policy design. However, measuring new seeds' contribution to overall yield increase nationwide is not easy because of a lack of suitable variables to reflect the potential of the new seeds in terms of enhancing yield.

To investigate the contribution of such seeds in Chinese agriculture, most studies compared different cultivars in uniform regional nurseries [4−7]; however, because of the natural differences between nurseries and growers' conditions, the measurement of these contributions is irregular and uncertain, particularly when the figures generated are then used for nationwide or regional estimation in dissimilar conditions [8−9]. Several studies have also employed the Analytic Hierarchy Process (AHP) method to assess the contribution of seed in terms of agricultural technological change; this is an effective tool for dealing with complex assessments by reducing the complex factors to be assessed to a series of pairwise comparisons and then synthesizing the results on the basis of the relative pairwise evaluations (both qualitative and quantitative) made by decision makers [10]. For example, He & He [11] used AHP to analyze the contributory share of each factor affecting agricultural technological change in Youzhong County, and the results suggested that seed accounted for the largest share of total technological progress at 25.64%; Zhao & Zhang [1] employed AHP to evaluate the contribution for each specific factor affecting agricultural technological change in China, and they concluded that seed made the largest contribution among all technological aspects, with a share of 29.55% of the total contribution. However, although a general assessment of seed contribution can thus be made using the AHP method, AHP requires analysts to set weighted values for each factor, and those values depend on the subjective judgments of the analysts, who may therefore reach different conclusions; it is thus impossible for this method to generate objective results.

When examining seed contribution to yield gains, many studies have focused on exploring the contribution of genetic improvements [8, 12−20]. For example, Feyerherm et al. [8] investigated the contribution of genetic improvement to wheat yield increases by employing a differential yielding ability (DYA) value established by computing the mean difference in yields between the given cultivar and a primary check cultivar over a set of years and locations within a geographical region of mutual adaptability. Duvick [14] stated that an Iowa-adapted time-series of hybrids representing the period from 1930 through 2001 showed a linear gain for grain yield of 77 kg/ha per year by employing a regression analysis based on trial data. And, a further examination of Duvick et al. [15] provided an estimate of 51% for the contribution of genetics, when trail yields are adjusted to the equivalent of average on-farm yields for Iowa during the period 1930 to 2001. Cargnin et al. [13] estimated the genetic progress of dryland wheat cultivars by computing the difference between the mean yield of a genotype one year and that of the previous year. Their results suggested that the mean estimated genetic progress for mean grain yield between 1976 and 2005 was 37 kg/ha per year. These studies have focused on quantifying the genetic contribution of seed to crop yield. While most previous studies used cultivar performance trial data to investigate the contribution of genetic improvement in cultivars, this creates problems in terms of extrapolating from performance in nurseries to those seen in actual growing conditions; results based on such trials are likely to overestimate the yield improvement on farms from the use of the new cultivars [21].

Yield gains nationally clearly depend on changes in cultivars, but they are only partially dependent on the genetic improvements in new seed cultivars; the extensive diffusion of such improved seed cultivars is another important aspect of enhancing crop yields. One way to enhance yield level is thus to improve seed cultivars, but another is to ensure the diffusion of such improved cultivars over large areas The actual impact even of pre-tested cultivars, taking into account the effects of weather, disease, and varying production conditions over large areas, thus remains highly uncertain, and the overall impact of seed cultivars in terms of both genetic improvement and diffusion of improved cultivars on nationwide yield is not currently well documented. The multiple confounding factors mean that only the overall contribution of cultivars, including both genetic improvement and diffusion, can be used to reflect progress in seed development and spread throughout the country. Nevertheless, this estimation is very important for planning purposes, and finding better ways to measure this overall contribution is a worthy goal in terms of governmental and political decision making.

The objective of this study is to develop a method from the perspective of agricultural economics to investigate the contribution of new seed cultivars to nationwide crop yield increases in China during 1980 and 2015. To facilitate this, the term contribution of new seed cultivars as used within this study will be deemed to refer to both the contributions made by genetic improvement in new cultivars and the diffusion of the improved cultivars; the term new seed cultivars refer to those seeds which have undergone genetic improvements and are adopted to replace current seed cultivars in general production in large areas.

2. Method

Normally, new seeds are developed and diffused into agricultural production regularly, and their diffusion may last for a few years. These new seeds' yielding ability can therefore only be fully demonstrated during their entire diffusion period, and hence estimating the contribution of seeds throughout the entire diffusion period is more scientific and reasonable than studying only one instance. In order to assess the contribution of seed cultivars to yield increases, the study period can be divided into several diffusion periods in terms of the replacement of the major cultivars for each crop and estimations of the overall contribution in each diffusion period made. Figure 1 presents the yield curve for each period. Suppose the new diffused seed cultivars lead to significant increase in crop yield with an average increase of h; in this case, the yield curve will also move above by h, in that the intercept will increase by h; and any decreases will also decrease the intercept. Here, h represents the contributory proportion of new seed cultivars to crop yield increases; the key to measuring new seed cultivars' contribution is therefore to estimate the h.

Figure 1. Yield curves in each diffusion period bordered on the time of change in adoption of new cultivars

The next key problem in terms of estimating seed cultivars' contribution to yield increases is the construction of a suitable yield model. Although previous studies have developed various yield models to predict crop yields [22−25], these have encountered several limitations; thus, taking into account that (1) sufficient data for constructing a production function for yield is generally unavailable; (2) crop yield is significantly sensitive to crop producer prices (a producer price is the average price or unit value received by farmers at the farm gate) [26−27]; and (3) a supply response model that contains crop producer prices is therefore more powerful in explaining changes in crop yield, the crop yield model used in this study is specified as a yield response model.

The yield response model is derived from the adaptive expectation theory which links farmers' behaviors to their expected prices and believes that farmers react not to the previous year's price but rather to the price they anticipate in the current year, and this expected price depends only to a limited extent on the previous year's price [28−29]. Formally, the adaptive expectation is written as

$$P_t^e = P_{t-1}^e + \lambda(P_{t-1} - P_{t-1}^e) \tag{1}$$

where P_t^e is the expected price in year t; P_{t-1}^e represents the expected price in year t–1; P_{t-1} represents the actual price in the previous year; and λ is the coefficient of expectation with $0 < \lambda \leq 1$, which reflects how much information producers retain in their current year's expectations from outcomes observed in the previous year. Farmers will revise their expected price in terms of the difference between the actual price and the expected price in the previous year, rather than simply arranging their production according to the actual price in the previous year [30].

The basic yield equation can be written as

$$Y_t = \alpha_0 + \alpha_1 P_t^e + \mu_t \tag{2}$$

where Y represents crop yield; μ is a random residual term, t is the year; and α_0 and α_1 are coefficients to be estimated. Unfortunately, the expected price cannot be observed, and thus these coefficients cannot be estimated. This problem can be solved by eliminating the expected price using mathematical transformation with equation (1) and (2), and the basic yield response model is obtained as

$$Y_t = \alpha + \beta_0 Y_{t-1} + \beta_1 P_{t-1} + v_t \tag{3}$$

where α turns out to be equal to $\alpha_0\lambda$, β_0 equals $1-\lambda$, β_1 equals $\alpha_1\lambda$, and v is a random residual that differs from μ. Most importantly, all variables are observed and therefore parameters can be estimated using observed data. This model is so called Nerlove model, which has been widely applied to estimate this dynamic process in crop production [26, 31−34]. Other factors, such as weather variability, disease, and production conditions, also affect crop yields; these factors are comprehensively represented by a proxy variable of lagged yield [35−36] in this model, which solves the problem of controlling for these factors when using trial data for estimation purposes.

In combination with the earlier analysis on division of various cultivar diffusion periods, to capture the contribution of different class of seed cultivars to increases in crop yields, a series of dummy variables representing various diffusion periods are incorporated into the basic yield response model, and parameters on these dummy variables capture the net average increases over the base period attributed to the adoption of the improved cultivars in each diffusion period. The resulting extended yield response model is shown as

$$Y_{it} = C + \beta_0 Y_{it-1} + \beta_1 P_{it-1} + \beta_i \sum_{i=2}^{n} D_i + \mu_{it} \tag{4}$$

where D indicates a series of dummy variables distinguishing diffusion periods for various seed cultivars with 1 for the given diffused period and 0 for the other years. Here β represents the net increase caused by new seed cultivar diffusion. If the adoption and diffusion of new seed cultivars significantly promotes crop yield, overall average yield during the diffusion period should rise, and β the coefficient on dummy variables is expected to take a positive sign; otherwise, a negative sign is expected. If the coefficient takes a negative sign, this indicates that the yield curve has decreased, and that the new seed cultivars have failed to enhance crop yields.

3. Data

Applying this method to estimate new cultivars' contribution to corn yield increases for six crops (rice, wheat, corn, soybeans, cotton, and rapeseed), and provincial panel data from 1980 to 2015 in China are used for estimation. Data on crop yields are obtained from the China Rural Statistical Yearbook. Price data are drawn from the National Cost and Return of Agricultural Products in China and are expressed in real terms with 1980 as the base year. Information on major cultivars diffused in each province is from the annual internal reports (from 1980 to 2015) provided by the Seed Administration of the Ministry of Agriculture of China.

In terms of changes in major diffused cultivars during the period 1980 to 2015, the diffusion period for seed cultivars of rice, wheat, corn, soybeans, cotton, and rapeseed can be divided into 6, 5, 5, 5, 6, and 5 segments, respectively. In the case of corn, the first period was from 1980 to 1986, when Zhongdan No.2 (ZD2) was planted in extremely large areas; the second period was from 1987 to 1994, when Danyu No.13 (DY13) replaced ZD2 as the most diffused cultivar; the third period ranged from 1995 to 1999, during which DY13 was moved from first place and Yedan No.13 (YD13) began to be adopted and diffused in most corn regions in China; the fourth period was from 2000 to 2003, when the major cultivar was changed to Nongda No.108 (ND108); and finally, the fifth period was from 2004 to 2015, when the top corn seed cultivar was Zhengdan No.958 (ZD958). Detailed changes for other crops see Table 1.

Table 1. Main seed cultivar and its diffusion period in China, bordered on the time of change in adoption of new cultivars

4. Results

4.1. Estimated results

The yield equation is a dynamic panel model, and when estimating dynamic panel models, the Ordinary Least Square (OLS) method is not appropriate, due to existence of endogeneity; thus, the Arellano-Bond dynamic panel generalized method of moments (GMM) is used to estimate the coefficients in this model. This method allows estimation in cases that would otherwise suffer from endogeneity [37]. The estimation in the current study was based on a relatively large sample size of provincial panel data, which improved the precision and stability of the coefficients, and hence increased the reliability of the results.

The estimated results are reported in Table 1. According to these estimations, most of the dummy variables are highly significant at the 0.1% significance level, with the exception of D2 for cotton, which strongly suggests that the model adequately captures the net increases in crop yield caused by the diffusion of new seed cultivars. The coefficients on the dummy variables represent the average increases in crop yield that can be attributed to new seed diffusion over the average yield in the base period. For instance, in the case of rice, the coefficient for D2 is 467.18, which implies that the new rice seed cultivars diffused in period two (1982 to 1985) increased the average yield by 467.2 kg/ha over the average in the base period (1980 to 1981). Likewise, in periods three (1986 to 1994), four (1995 to 1999), five (2000 to 2007), and six (2008 to 2015), the average increases over the base period were 708.5, 1121.4, 1160.8, and 1303.8 kg/ha, respectively. Overall, the average increase in rice yield due to new rice seed diffusion rose gradually over time, indicating significant improvements in yielding ability in the new rice cultivars.

Furthermore, the estimation results contain information that allows for a quantitative comparison of seed contribution between any two periods. As an instance of comparison between adjacent periods, still focusing on the case of rice, the magnitudes of coefficients D3 and D2 were 708.5 and 467.2; the difference between D3 and D2 was thus 241.3, implying that rice seed contributions in period three (1986 to 1994) were 241.3 kg/ha greater than those of the cultivars adopted in period two (1982 to 1985). This suggests that the seeds used in period three were improved relative to the seed diffused in period two. The figures do suggest that new seed cultivars do not always improve crop productivity, however; for example, the coefficients on D5 and D4 for wheat are 523.0 and 532.2, creating a difference in value between the two periods of −9.2, which implies that the wheat cultivars diffused in period five (2008 to 2015) failed to increase wheat yield over the cultivars used in period four (2003 to 2008). Similar comparisons can be made for any two periods using this estimation.

Table 2. Estimated results for crop yield equation using Arellano-Bond GMM

4.2. Caltivar contribution

Table 3 summarizes the net increases attributed to new seed cultivars' diffusion periods for 6 crops over both the base period and the previous period. Generally, the seed contribution to yield increases rose gradually, although small decreases were noted in period five for wheat and in period four for corn. This reflects gradual improvements in newly developed seed cultivars and their diffusion over time. Rice and corn exhibited significant increases in terms of absolute contribution, and were the only two crops in which seed contribution over the base period exceeded 1000 kg/ha; the cultivars' contribution in the final period reached 1303.8 kg/ha and 1179.5 kg/ha, respectively, 2.8 and 2.5 times the respective contribution in period two. Wheat, despite being a staple food grain, showed a current contribution of new cultivars that was relatively low among the three main grains at 523.0 kg/ha, only around half the contribution made by rice and corn cultivars, and only double that seen in the second period for wheat. In contrast, the current contributions for soybeans, cotton, and rapeseed were measured at 316.9, 196.8, and 414.2 kg/ha, respectively, almost 3, 8, and 4 times more than the respective contributions for these crops in period two.

Table 3. Absolute contribution of new cultivars to crop yield increases in various diffusion periods (kg/ha)

Table 4 summarizes the contribution share of new seed cultivars to yield increases for each crop. The contribution share is calculated by dividing the yield increase caused by new cultivar diffusion by the total yield increase during the diffusion period. The average yield is based on official statistical data. For example, the rice average yield in the base period (1980−1981) was 3957.3 kg/ha, and this increased to 4462.5 kg/ha in period two (1982−1985), a total improvement of 705.2 kg/ha; of this, new seed diffusion contributed 467.2 kg/ha to the total increase, and thus the contribution of the new seed cultivars was calculated as 66.3% in the second diffusion period. Likewise, in the sixth diffusion period, the rice yield average grew to 6679.2 kg/ha, an increase of 2721.9 kg/ha over the average in the base period, of which 1303.8 kg/ha was attributed to new seed diffusion in the period; thus, the contribution share of new seeds for this diffusion period was 47.9%. The seed contribution over the previous period for period two is naturally the same as that over the base period, because the comparison is made between the same two periods. In period three, the average rice yield was 5230.1 kg/ha, 567.6 kg/ha higher than the average of 4662.5 kg/ha in the second period, and the increase attributed to seed replacement over period two was calculated as 241.3 kg/ha (708.5−467.2); thus, the contribution over the previous period of new seed cultivars in period three was 42.5%. More detailed changes in crop yield and new seed cultivar contributions are displayed in Appendixes A1 to A6.

Table 4. Contribution of new cultivars to crop yield increases in their diffusion period (%)

The contribution rate is a relative indicator that reflects the contribution share of the new seed cultivars to the total increase in yield. A decreasing contribution rate thus does not mean that the absolute contribution of new seeds to yield increases has necessarily shrunk; when other factors cause sharp increases in crop yield, the contribution share for new seed cultivars may be reduced despite the absolute net increases due to new cultivars continuing. For instance, the rice seed contribution during the period 2008 to 2015 decreased to 47.9%, down 3.3 percentage points from that in the previous period from 2000 to 2007. However, in terms of absolute value of contribution, new seed diffusion during 2008 to 2015 enhanced rice yields by 1303.8 kg/ha over the base period, while new seed adoption in the period from 2000 to 2007 gave an absolute contribution of 1160.8 kg/ha, 143.0 kg/ha less than period 2008 to 2015, during which the contribution rate nevertheless decreased compared to the previous period (2000 to 2007). The reason for this may be the significant increases in input factor during 2008 and 2015, a period which witnessed significant increases in input usage that resulted in yield increases, leading naturally to the contribution share of new seed cultivars appearing relatively small.

5. Conclusion

Estimating the contribution of new seed cultivars to nationwide yield increases is a challenging but essential task. This study developed a method to estimate the contribution of new seed cultivars to yield increases by employing a yield response model in which a series of dummy variables were included to capture the contributions of various cultivar classes during their diffusion periods, which were in turn defined by the replacement of major cultivars. Within this method, the coefficients for the dummy variables represented the net increases attributed to new cultivars over the base period. In a departure from most previous studies, this study developed a method that aims to estimate the overall contribution, rather than only the genetic contribution, of such cultivars to yield gains, thus attributing improvements from new seeds to both breeding and diffusion; these contributions were estimated by capturing changes in the intercept of the yield curve. Further, statistical yield data on farm fields was used for estimation, allowing the estimated contribution to represent the actual impact of new cultivars in the field. Using this method, the overall contribution of new seed cultivars for six crops (rice, wheat, corn, soybeans, cotton, and rapeseed) was estimated. The estimated results indicated that adoption of new seed cultivars has significantly enhanced crop yields in China during the past three decades; in particular, the seed contributions for rice and corn in the most current diffusion period were both more than

1000 kg/ha, accounting for nearly 50% of the total increase over the base period, indicating that seed cultivars have been an essential factor driving increase in rice and corn yield in China.

The suggested method involves only few variables, and is thus relatively uncomplicated; the data required can also be easily collected from yearbooks or official reports. Based on these facts, this method can be easily utilized in practical applications. In addition, the contribution indicator thus generated can be estimated and reported on annually by means of simply updating the annual data, satisfying governmental demands for annual assessments of the progress of breeding programmes and the work of new cultivar diffusion. Corresponding policies for agricultural development, particularly for the seed sector, could therefore be designed with reference to regular tracking assessments, making this a method that could easily be applied to actual measurement of progress in seed breeding technologies and agricultural development.

Appendix A

Table A1. Contribution of new cultivars to rice yield increases in each diffusion period (kg/ha, %)

Diffusion period	Average yield	Over the base period			Over the previous period		
		Total increase	Increase caused by new cultivars	Cont. of new cultivars	Total increase	Increase caused by new cultivars	Cont. of new cultivars
Base (80−81)	3957.3	--	--	--	--	--	--
2 (82−85)	4662.5	705.2	467.2	66.3	705.2	467.2	66.3
3 (86−94)	5230.1	1272.8	708.5	55.7	567.6	241.3	42.5
4 (95−99)	6185.3	2228.0	1121.4	50.3	955.2	412.9	43.2
5 (00−07)	6226.8	2269.5	1160.8	51.2	41.5	39.3	94.8
6 (08−15)	6679.2	2721.9	1303.8	47.9	452.3	143.1	31.6

Note: %, the unit for contribution.

Table A2. Contribution of new cultivars to wheat yield increases in each diffusion period (kg/ha, %)

Diffusion period	Average yield	Over the base period			Over the previous period		
		Total increase	Increase caused by new cultivars	Cont. of new cultivars	Total increase	Increase caused by new cultivars	Cont. of new cultivars
Base	2175.2	--	--	--	--	--	--

(80−89)							
2 (90−94)	2783.0	607.9	272.4	44.8	607.9	272.4	44.8
3 (95−02)	3105.0	929.9	325.5	35.0	322.0	53.1	16.5
4 (03−08)	3448.3	1273.2	532.2	41.8	343.3	206.6	60.2
5 (09−15)	3745.6	1570.4	523.0	33.3	297.3	−9.2	−3.1

Note: %, the unit for contribution.

Table A3. Contribution of new cultivars to corn yield increases in each diffusion period (kg/ha, %)

Diffusion period	**Average yield**	**Over the base period**			**Over the previous period**		
		Total increase	**Increase caused by new cultivars**	**Cont. of new cultivars**	**Total increase**	**Increase caused by new cultivars**	**Cont. of new cultivars**
Base (80−86)	2852.4	--	--	--	--	--	--
2 (87−94)	3642.5	790.1	479.1	60.6	790.1	479.1	60.6
3 (95−99)	4494.9	1642.5	794.1	48.4	852.4	315.0	37.0
4 (00−03)	4633.2	1780.8	787.6	44.2	138.3	−6.5	−4.7
5 (04−15)	5330.4	2477.9	1179.5	47.6	697.1	391.9	56.2

Note: %, the unit for contribution.

Table A4. Contribution of new cultivars to soybeans yield increases in each diffusion period (kg/ha, %)

Diffusion period	**Average yield**	**Over the base period**			**Over the previous period**		
		Total increase	**Increase caused by new cultivars**	**Cont. of new cultivars**	**Total increase**	**Increase caused by new cultivars**	**Cont. of new cultivars**
Base (80−86)	1078.0	--	--	--	--	--	--
2 (87−94)	1331.1	253.1	106.9	42.2	253.1	106.9	42.2
3 (95−99)	1581.1	503.1	210.7	41.9	250.0	103.8	41.5
4 (00−05)	1723.8	645.8	294.9	45.7	142.7	84.2	28.6
5 (06−15)	1843.9	765.9	316.9	41.4	120.1	22.1	18.4

Note: %, the unit for contribution.

Table A5. Contribution of new cultivars to cotton yield increases in each diffusion period (kg/ha, %)

Diffusion period	Average yield	Over the base period			Over the previous period		
		Total increase	Increase caused by new cultivars	Cont. of new cultivars	Total increase	Increase caused by new cultivars	Cont. of new cultivars
Base (80−89)	442.9	--	--	--	--	--	--
2 (90−95)	546.9	104.0	24.4	23.5	104.0	24.4	23.5
3 (96−98)	669.8	226.9	82.1	36.2	122.9	57.6	46.9
4 (99−03)	795.5	352.6	141.8	40.2	125.7	59.7	47.5
5 (04−06)	825.9	383.1	167.7	43.8	30.5	25.9	85.1
6 (07−15)	1021.7	578.8	196.8	34.0	195.8	29.1	14.8

Note: %, the unit for contribution.

Table A6. Contribution of new cultivars to rapeseed yield increases in each diffusion period (kg/ha, %)

Diffusion period	Average yield	Over the base period			Over the previous period		
		Total increase	Increase caused by new cultivars	Cont. of new cultivars	Total increase	Increase caused by new cultivars	Cont. of new cultivars
Base (80−86)	987.0	--	--	--	--	--	--
2 (87−00)	1250.8	263.8	104.6	39.6	263.8	104.6	39.6
3 (01−04)	1562.8	575.8	300.1	52.1	312.0	195.5	62.7
4 (05−09)	1762.2	775.2	363.4	46.9	199.4	63.3	31.7
5 (10−15)	1879.6	892.6	414.2	46.4	117.4	50.8	43.3

Note: %, the unit for contribution.

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Tables and Figures

Table 1. Main seed cultivar and its diffusion period in China, bordered on the time of change in adoption of new cultivars

Period	Rice	Wheat	Corn	Soybean	Cotton	Rapeseed
1	--	BN3217	ZD2	YJ5	LM1	XN302
(Base)	(80−81)	(80−89)	(80−86)	(80−86)	(80−89)	(80−86)
2	SY2	YM5	DY13	HF25	ZM12	ZY821
	(82−85)	(90−94)	(87−94)	(87−94)	(90−95)	(87−00)
3	SY63	YM18	YD13	HF35	SM3	HZ4
	(86−94)	(95−02)	(95−99)	(95−99)	(96−98)	(01−04)
4	GY22	ZM9023	ND108	SN14	XM33	QY7
	(95−99)	(03−08)	(00−03)	(00−05)	(99−03)	(05−09)
5	LYP9	JM22	ZD958	ZH13	ZM35	QY10
	(00−07)	(08−15)	(04−15)	(06−15)	(04−06)	(10−15)
6	YLY1	--	--	--	LMY28	--
	(08−15)	--	--	--	(07−15)	--

Note: values in parentheses indicate diffusion period for the main cultivars. SY No.2, Shanyou No.2; SY No.63, Shanyou No.63; GY No.22, Gangyou No.22; LYP No.9, Liangyoupei No.9; YLY No.1, Yliangyou No.1; BN 3217, Bainong No.3217; YM 5, Yangmai No.5; YM 18, Yumai No.18; ZM 9023, Zhengmai No.9023; JM 22, Jimai No.22; ZD No.2, Zhongdan No.2; DY 13, Danyu No.13; YD 13, Yedan No.13; ND 108, Nongda No.108; ZD 958, Zhengdan No.958; YJ 5, Yuejin No.5; HF 25, Hefeng 25; HF 35, Hefeng No.35; SN 14, Suinong No.14; HF 45, Hefeng No.45; ZH13, Zhonghuang No.13; LM1, Lumian No.1; ZM12, Zhongmian No.12; SM3. Simian No.3; XM33, Xinmian No.33; ZM35, Zhongmian No.35; LMY28, Lumianyan No.28; XN302, Xinan No.302; HZ4, Huaza No.4; QY7, Qinyou No.7; QY10, Qinyou No.10.

Table 2. Estimated results for crop yield equation using Arellano-Bond GMM

Coefficients	Rice	Wheat	Corn	Soybean	Cotton	Rapeseed
C	2568.53***	590.55***	1874.55***	527.95***	98.82*	136.27*
	(435.63)	(132.32)	(316.20)	(123.28)	(55.39)	(71.55)
Yt-1	0.34***	0.59***	0.38***	0.48***	0.63	0.47***
	(0.07)	(0.08)	(0.09)	(0.05)	(0.06)	(0.05)
Pt-1	20.45***	22.44***	7.12	2.56	0.51**	2.28***
	(8.21)	(5.10)	(10.85)	(1.92)	(0.24)	(0.50)
D2	467.18***	272.42***	479.11***	106.92***	24.43	104.58***
	(140.17)	(56.39)	(79.84)	(27.93)	(20.20)	(19.31)
D3	708.50***	325.52***	794.13***	210.67***	82.07***	300.09***
	(150.52)	(65.74)	(149.89)	(50.31)	(21.23)	(34.50)
D4	1121.43***	532.16***	787.62***	294.86***	141.79***	363.37***
	(197.35)	(83.96)	(112.59)	(56.67)	(24.76)	(39.68)
D5	1160.76***	523.01***	1179.54***	316.91***	167.73***	414.16***
	(220.73)	(96.55)	(207.62)	(59.99)	(29.30)	(41.93)
D6	1303.81***	--	--	--	196.78***	--
	(237.41)	(--)	(--)	(--)	(37.77)	(--)
Obs.						

Note: values in parentheses are standard errors. ***, **, * indicates 1%, 5%, and 10% significance level, respectively.

Table 3. Absolute contribution of new cultivars to crop yield increases in various diffusion periods (kg/ha)

Period	Over the base period						Over the previous period					
	Rice	Wheat	Corn	Soybean	Cotton	Rapd.	Rice	Wheat	Corn	Soybean	Cotton	Rapd.
1	--	--	--	--	--	--	--	--	--	--	--	--
(Base)	(80−81)	(80−89)	(80−86)	(80−86)	(80−89)	(80−86)	(80−81)	(80−89)	(80−86)	(80−86)	(80−89)	(80−86)
2	467.2	272.4	479.1	106.9	24.4	104.6	467.2	272.4	479.1	106.9	24.4	104.6
	(82−85)	(90−94)	(87−94)	(87−94)	(90−95)	(87−00)	(82−85)	(90−94)	(87−94)	(87−94)	(90−95)	(87−00)
3	708.5	325.5	794.1	210.7	82.1	300.1	241.3	53.1	315.0	103.8	57.6	195.5
	(86−94)	(95−02)	(95−99)	(95−99)	(96−98)	(01−04)	(86−94)	(95−02)	(95−99)	(95−99)	(96−98)	(01−04)
4	1121.4	532.2	787.6	294.9	141.8	363.4	412.9	206.6	−6.5	84.2	59.7	63.3
	(95−99)	(03−08)	(00−03)	(00−05)	(99−03)	(05−09)	(95−99)	(03−08)	(00−03)	(00−05)	(99−03)	(05−09)
5	1160.8	523.0	1179.5	316.9	167.7	414.2	39.3	−9.2	391.9	22.1	25.9	50.8
	(00−07)	(08−15)	(04−15)	(06−15)	(04−06)	(10−15)	(00−07)	(08−15)	(04−15)	(06−15)	(04−06)	(10−15)
6	1303.8	--	--	--	196.8	--	143.1	--	--	--	29.1	--
	(08−15)	--	--	--	(07−15)	--	(08−15)	--	--	--	(07−15)	--

Note: with period in parentheses.

Table 4. Contribution of new cultivars to crop yield increases in their diffusion period (%)

Period	Over the base period						Over the previous period					
	Rice	Wheat	Corn	Soybean	Cotton	Rapd.	Rice	Wheat	Corn	Soybean	Cotton	Rapd.
1	--	--	--	--	--	--	--	--	--	--	--	--
(Base)	(80−81)	(80−89)	(80−86)	(80−86)	(80−89)	(80−86)	(80−81)	(80−89)	(80−86)	(80−86)	(80−89)	(80−86)
2	66.3	44.8	60.6	42.2	23.5	39.6	66.3	44.8	60.6	42.2	23.5	39.6
	(82−85)	(90−94)	(87−94)	(87−94)	(90−95)	(87−00)	(82−85)	(90−94)	(87−94)	(87−94)	(90−95)	(87−00)
3	55.7	35.0	48.4	41.9	36.2	52.1	42.5	16.5	37.0	41.5	46.9	62.7
	(86−94)	(95−02)	(95−99)	(95−99)	(96−98)	(01−04)	(86−94)	(95−02)	(95−99)	(95−99)	(96−98)	(01−04)
4	50.3	41.8	44.2	45.7	40.2	46.9	43.2	60.2	−4.7	28.6	47.5	31.7
	(95−99)	(03−08)	(00−03)	(00−05)	(99−03)	(05−09)	(95−99)	(03−08)	(00−03)	(00−05)	(99−03)	(05−09)
5	51.2	33.3	47.6	41.4	43.8	46.5	94.8	−3.1	56.2	18.4	85.1	43.3
	(00−07)	(08−15)	(04−15)	(06−15)	(04−06)	(10−15)	(00−07)	(08−15)	(04−15)	(06−15)	(04−06)	(10−15)
6	47.9	--	--	--	34.0	--	31.6	--	--	--	14.8	--
	(08−15)	--	--	--	(07−15)	--	(08−15)	--	--	--	(07−15)	--

Note: with period in parentheses.

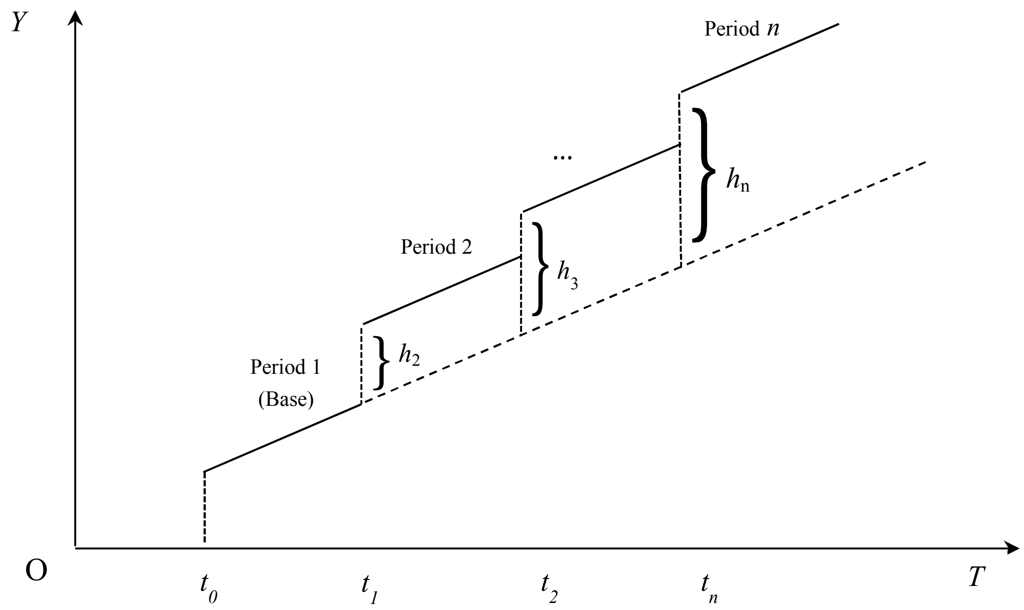

Figure 1. Yield curves in each diffusion period bordered on the time of change in adoption of new cultivars