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Genetically Modified Rice, Yields and Pesticides: Assessing Farm-level Productivity and Health Effects in China

Jikun Huang,[1*] Ruifa Hu,[1], Scott Rozelle[2] and Carl Pray[3]

1. Center for Chinese Agricultural Policy, Institute of Geographical Sciences and Natural Resource Research, Chinese Academy of Sciences, Jia 11, Datun Road, Beijing 100101, China

2. Shorenstein Asia-Pacific Research Center, Freeman Spogli Institute for International Studies, Stanford University

3. Department of Agricultural, Food, and Resource Economics, Rutgers University

* To whom correspondence should be addressed:

Name: Jikun Huang
Address: Center for Chinese Agricultural Policy
Chinese Academy of Sciences
Jia 11, Datun Road, Anwai, Beijing 100101
Tel: (86)-10-64889833
Fax: (86)-10-64856533
Email: jkhuang.ccap@igsnrr.ac.cn

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Abstract

Although genetically modified crops are being grown on increasing larger areas in both developed and developing countries, with few minor exceptions, there has been almost no country that has commercialized a genetically modified major food crop. One reason may be that is unclear how the commercialization of genetically modified crops will help poor, small farmers. The objective of this paper is to report on the results of an economic analysis that uses three years of data from a series of quasi-experimental areas in China's GM rice program that were carried out in the fields of small and relative poor producers in two provinces in China. The paper attempts to answer two key questions: Does GM rice help reduce pesticides in the fields of farmers? Do the new varieties of GM rice increase the yields of farmers? Based on the results, the paper shows that the use of GM rice by farmers in pre-production trials allows farmers to reduce pesticide use and labor input, increase yields and improve their health. The paper concludes by arguing that the commercialization of GM rice in China could have consequences that exceed the direct impacts on China's farmers and could be a key step in breaking the world's current plant biotechnology logjam.

Keywords: Biotechnology, Rice, Productivity, Health, China

JEL Codes: Q12; Q16; O33

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One of the early promises by the supporters of agricultural biotechnology was that this set of research tools could make a major contribution to the reduction of world hunger. It is now 25 years since some of those early promises were made and a decade since genetically modified (GM) crops were first grown commercially, but the only substantial way that biotechnology has contributed to the well-being of the hungry is through higher incomes from the production of GM cotton (Huang et al., 2002). Only a small set of countries have extended GM food crops and most of these in a relatively minor way (James, 2004; 2005). Now China is on the threshold of starting to fulfill the promise of more food for the poor through the introduction of rice varieties that can resist important insect pests and disease. This paper presents the first evidence from the fields of farmers in the economic literature on whether GM rice can really start to deliver on its promise or whether this is another set of unfounded promises from the supporters of biotechnology.

Although the contribution of agricultural technology to the expansion of rice output and income growth in China and other developing countries during the past 40 years are substantial and well documented (Lin 1994, Barker et al., 1985, Evenson et al., 1996), there is still a need in the future for both rapid rises in agricultural productivity and ways to reduce some of the adverse consequences of modern agricultural practices (Borlaug, 2000; Byerlee et al., 2000). From a nation facing widespread famine in the 1940s and 1950s, Green Revolution varieties, investments in water control and the intensification of chemical input use in China raised food production to levels that no one would have dared predict (Stone, 1988). Past success, however, does not guarantee abundant food and profitability in the coming decades. Rosegrant et al. (2001) estimate that China's cereal production must continue to rise by about 40 percent to satisfy most of the demand of the nation's population by 2020. With most available cultivated land already in use, the future growth of output in China, as elsewhere in the developing world, will have to rely on rising yields (Pingali et al., 1997; Jin et al., 2002). There also have been negative consequences associated with the use of conventional varieties. For example, the high levels of pesticide use (China is the largest pesticide user in the world), especially in the case of rice (rice farmers use more than 40% of all pesticides that are used on the nation's field crops excluding vegetable and fruits), have led to a case in which the health of tens of millions of farmers are being adversely affected, costing the nation millions in lost labor days, billions of yuan in increased health costs and an immeasurable amount in suffering (Pray et al., 2001; Huang et al., 2001).

While most scientists believe that agricultural biotechnology can provide new sources of productivity growth and address some of the negative effects of conventional agronomic techniques for producers of rice and other basic food crops in China and other developing countries, at present they are primarily used for industrial crops like cotton and grain for animal feed such as yellow maize and soybeans (James, 2005). In the late 1980s and 1990s government research in many developing nations often funded by the Rockefeller Foundation began ambitious rice biotech research programs to develop new rice varieties that would increase yields and nutrition, reduce input use and make the rice plant (as well as those of other food crops) more tolerant to both biotic and abiotic stresses (Evenson et al., 1996). This research led to a major increase in knowledge about the rice plant and rice genetics and the development of conventional and genetically modified (GM) rice varieties that could help producers in developing countries. New conventional varieties with resistance to bacterial leaf blight developed through molecular aided selection are now available to farmers in Indonesia and China. Scientists in China, India and Costa Rica are conducting field trials for new GM varieties of insect and disease resistant rice; there are reports that GM rice has been commercialized in Iran (James, 2005). However, due to government indecision, evolving biosafety regulatory systems, consumer resistance, and trade concerns no major GM rice varieties have been approved for commercial use anywhere in the developing world.

The difficulties of commercializing GM rice appear to be affecting the amount and direction of public and private biotech research also. According to interviews that one of our coauthors has been conducting in developing countries outside of China over the past several years, it has been noted that government scientists in India are faced with increasing difficulty in finding locations for the trials of GM rice, and because of increasing costs due to the need to protect the fields from anti-biotech organizations, many research organizations are pulling back from trying to develop GM varieties and simply publishing their research results or working on industrial crops like cotton where GM varieties can be commercialized. The private sector also is cutting back because consumer resistance to GM products and because of the rising cost of commercializing new products. For example, Monsanto in the United States discontinued work on rice in the late 1990s and other companies such as Syngenta and Bayer have sharply cut back on their rice research programs in recent years.

As a result, except for in a number of relatively minor locations, no GM rice has been commercialized anywhere in the world (except for small areas in Iran) and little is in the pipeline in most countries. In fact, with the exception of Bt white maize in South Africa, where Bt white maize is primarily being grown by large, relatively wealthy farmers (James, 2004), there are few cases in which GM staple food crops are being grown. Even in China, a country that initially aggressively commercialized Bt cotton and invested heavily into research on GM food crops, policy makers have not allowed the commercialization of any major food crops despite the fact GM crops have been in experimental trials since 1999.

In addition to the actions of small but vocal urban consumer groups that have actively discouraged the commercialization of GM food crops, one reason that commercialization has not proceeded, especially in developing countries such as China that are less pressured by anti-GM activist organizations, is that there has been little independent evidence on whether GM food crops would really improve the income and well-being of farmers, especially those who are poor. Often regulators and policy makers have to take the word of the government scientists and companies who developed and are promoting these GM products.

The objective of this study is to report on the results of an economic analysis that uses three years of data from key experiments in China's GM rice program that were carried out in the fields of small and relative poor producers in two sites in China. The paper attempts to answer two questions: Does GM rice help reduce pesticides in the fields of farmers? Do the new varieties of GM rice increase the yields of farmers? Based on the results, the paper shows that the use of GM rice by farmers in pre-production trials allows farmers to reduce pesticide use and labor inputs, increase yields and improve the health of farmers. The paper concludes by arguing that the commercialization of GM rice in China could have consequences that exceed the direct impacts on China's farmers and could be a key step in breaking the world's current plant biotechnology logjam.

China's GM Rice Research Program

China's modern biotechnology program, begun in the 1980s, has grown into the largest initiative in the developing world (Huang et al., 2002). A recent survey by the authors of agricultural biotechnology research investment in 2004 shows that the government's spending on agricultural biotechnology (including plants, animals and microorganisms) reached RMB 1.647 billion, which is equivalent to US $199 million at current exchange rates and US $954 million in purchasing power parity terms (Table 1, column 1). Between the mid-1980s and 2000, annual plant biotechnology spending also rose fast, more than doubling each five years for the first 15 years (column 2). Between 2000 and 2003, plant biotechnology investment continued to accelerate, more than doubling during the three-year period.

Although the success of GM cotton in China initially attracted the attention of research administrators that allocated cotton scientists nearly 15 percent of national plant biotechnology research expenditures (despite the fact that the crop accounts for only about five percent of China's sown area), rice scientists also have been provided with increasing financial resources (Table 1, column 3). In the late 1980s each year rice scientists were provided with US $2 to 3 million (at the official exchange rates). By 2003, rice scientists were allocated nearly US $24 million (or $115 in PPP), accounting for nearly 20 percent of plant biotechnology spending (which in the case of rice is almost its sown area share). Although estimates of world spending on rice biotechnology are not available, given the low priority accorded by funding agencies to rice in nations with the largest biotechnology programs (such as the US and the UK), it is almost a certainty that China's public investment into rice biotechnology exceeds that of any other nation.

China's rice biotechnology research program has generated a wide array of new technologies that are at all stages of the research and development process. In China the Ministry of Agriculture must grant a company or research institute a permit before any GM plant can be commercialized. Before such a permit is granted, however, China's bio-saftey procedures require transgenics crops to pass through three phases of trials: field trials (equivalent to small-scale, contained trials in the US); environmental release trials (equivalent to controlled farmer-field trials in the US) and pre-production trials (larger-scale, farmer-field trials—that are not controlled by the scientist). Pre-production trials are not required in the US.

Many types of transgenic rice varieties and hybrids have reached and passed the field trial and environmental release trial phases of China's bio-safety testing since the late 1990s. Transgenic Bt rice varieties that are resistant to rice stemborer and leaf roller were approved for environmental release trials in 1997 and 1998 (Zhang et. al, 1999). In experimental fields in Wuhan in 1999 Bt hybrid Xianyou 63 yielded 28.9 percent more than non hybrid Xianyou 63 in the presence of natural attacks of leaf roller and natural and induced attacks of yellow stem borer; pesticides were not applied to either variety (Tu et al., 2000a). Other scientists introduced the CPTi gene into rice creating rice varieties with another type of resistance to rice stemborer and this product was approved for environmental release trials in 1999 (NCBED, 2000). Transgenic rice with Xa21 and Xa7 genes for resistance to bacterial blight were approved for environmental release trials since 1997 (NCBED, 2000). Trials of the IRRI variety IR72 transformed to express the Xa21 gene in 1998 and 1999 were shown in experimental fields to give a high-level of protection against bacterial blight outbreaks (Tu et al., 2000b). Interviews also found that although environmental release trials have not begun, field trials have been underway since 1998 for transgenic plants with herbicide tolerance (using the Bar gene) as well as varieties expressing drought and salinity tolerance in rice.

Of all of the work being done in field and environmental release trials, four transgenic rice hybrids, which have been engineered to be resistant to major pests in China, have advanced to the final stage of field trials, the pre-production trials stage. Two insect resistant hybrids—GM Xianyou 63 and Kemingdao—contain the stemborer-resistant Bt genes. According to experimental trial data, the Bt varieties are resistant to three stemborers in China—*Tryporyza incertulas* Walker, *Chilo suppressalis* Walker and *Cnaphalocrocis medinalis* Guenee (Zhu et al., 2003). The hybrid GM II Youming 86 contains the CPTi gene which provides resistance to six pests, the same pests that are targets of varieties containing Bt plus *Sesamia inferens* Walker, *Parndra guttata* Bremeret Grey and *Pelopidas mathias* Fabricius. MOA reports that in 2000 and 2001 stemborers affected between 68 to 75 percent of China's rice area (MOA, 2002). Given that China's rice area is nearly 30 million hectares, this means that the main pests targeted by China's experimental GM rice varieties (that are currently in pre-production trials) affect more than 20 million hectares annually, nearly 13% of the world's total rice sown area. A fourth hybrid contains the Xa21 genes that provide resistance to bacterial blight, one of the most prevalent diseases in rice production areas in central China (Zhu et al., 2003).

According to the scientists that have been working to develop the new GM rice technologies, several varieties have had successful agronomic, environmental release but to date have not been approved for commercial use (Zhu et al., 2003). It is claimed approval has been held up by pressure from environmental and trade interest groups in China and by those that do not want to see China bear the risk of being the first large nation to commercialize a major GM food crop.

In place of commercialization, after a new GM variety passes the environmental release stage of the bio-safety testing process, the variety must pass through pre-production trials. Preproduction trials are a relatively new phase of testing that is required for GM food crops before approval for commercialization can be given. According to China's bio-safety regulations, the total area for each pre-production trial should be more than 30 mu but not exceed 1000 mu, or 66.7 hectares (MOA, 2005). Pre-production trials are allowed to be carried out in no more than 2 provinces in which the environmental release trails were conducted. When the preproduction trials are carried out in the fields of farmers, the trials are largely unsupervised; farmers are given the seed and, except for periodic monitoring, scientists do not intervene in the cultivation process.

Over time the number of villages with Bt rice pre-production trials has grown. For example, according to our contacts in Hubei province, the number of villages in which farmers cultivated GM Xianyou 63 (which were developed by scientists from Central China Agricultural University—CCAU), rose from 4 in 2002 to 7 in 2003 and to 11 in 2004 (Table 2). Because the location of the counties and villages sometimes change over time (especially between 2003 and 2004), in total we visited 15 preproduction trials villages located in 6 counties in Hubei between 2002 and 2004. The pre-production trials for GM II-Youming 86 developed by the Chinese Academy of Sciences and the Fujian Academy of Agricultural Sciences were initially only being conducted by technicians in 4 rice experimental stations; 3 of the stations were in Fujian province and 1 was in Hubei province. In 2002 and 2003 scientists carried out pre-production trials for GM II-Youming 86 in 1 village in Fujian province (Shixi Village in Shunchang County—Table 2). In 2004, the trials expanded into 1 additional village (Nanhui Village in Taining County). In total, then, pre-production trials between 2002 and 2004 for GM Xianyou 63 and GM II Youming 86 were being carried out in 17 villages located in 8 counties (Table 2, bottom rows) and 4 experiment station locations (Table 2, footnote). In this study only GM rice plots (as well as non-GM rice plots—which are used as controls) that are cultivated by individual farmers that live in villages outside experiment stations are analyzed. Before collecting data we confirmed by in-depth interviews with local leaders and farmers that farmers in these areas are only provided seed and are cultivating GM rice *without the assistance of breeders or their staffs*. In contrast, we did not conduct surveys in experiment stations since rice plots in the pre-production trials in the experiment stations are being cultivated by farmer-cum-technicians working under the direction of the scientists.

Data

Our three-year survey was conducted in 2002 to 2004 by enumeration teams trained and led by the authors and was designed to collect information allowing the comparison of the performance of GM rice and non-GM rice under field conditions.

The total number of observations from the three years of survey work includes 320 rice producing households—73 in 2002; 104 in 2003; 143 in 2004. These households were randomly chosen by the authors from the population of all of the farmers in the pre-production village (whether they were included in the Bt rice experiment or not). According to the protocol of the pre-production trials, households in the sample were randomly assigned to be in the project. Although this occurred in some villages, it is unclear whether the random assignment was carried out strictly in all villages. Therefore, in our analysis we compare the nature of Bt and non-Bt rice households in order to understand if the characteristics of Bt rice producing households differ from those of non-Bt rice producing households.

In addition, we also designed the survey so that the enumerators, using standard, sit-down interviewing techniques relying on producer recall of inputs and outputs (for the current year), collected information *at the plot level* in order to be able to distinguish production practices (including level of inputs) that are used on plots with both GM and non-GM rice. Given the focus on insect-resistant varieties, respondents were asked detailed questions about the total amount of pesticides used on each plot, the value of the pesticide and the number of sprayings. In total, the survey obtained data from 584 rice production plots, 211 plots planted with GM rice and 373 plots planted with non-GM-rice. Among the 73 households in the 2002 survey, 37 planted non-GM rice only, 25 planted both GM and non-GM rice varieties and 11 planted GM rice only. In 2003, of the 104 households, 36 planted non-GM rice only, 52 planted both GM and non-GM rice varieties and 16 planted GM rice only. In 2004, of the 143 households, 60 planted non-GM rice only, 42 planted both GM and non-GM rice varieties and 41 planted GM rice only (Table 3). Therefore, in total during the three years of the study, we have 119 household-level observations (25+52+42) in which the household cultivated both GM and non-GM plots during a single year.

In addition, there was also variation over time among the sample households in their status as a household the cultivated Bt rice or not. Among the total 213 different households that were interviewed, there were 41 households that were in the survey for two years and 33 households that were in the survey all three years. Of these, 35 households at some point during the survey switched the status of at least one plot from GM rice to non-GM rice (or vice versa). Since the survey also was designed to track plots of farmers over time, in the sample we have 107 households that have at some point of time in the survey produced both GM and non-GM rice (in some cases it was producing one Bt plot and one non-Bt plot during a single year; in other cases it was producing Bt on one plot during one year and producing non-Bt on the plot during the next).

Besides collecting detailed, plot-specific information on inputs and outputs, the survey also contained a number of questions focused on understanding the economic and health effects of using insect-resistant rice varieties. Farmers recounted the prices paid for all inputs and the prices that they received for their output. All of the transactions, except for the provision of the seed to the farmers, were conducted on free markets with no assistance from the research team or local government officials. These data are used mainly to calculate whether or not there were any productivity effects associated with the adoption of GM rice within the sample households.

The high incidence of pesticide-related illness in households in developing countries, including China also created an interest in tracking the health effects of GM rice adoption (Antle and Pingali, 1994; Huang et al. 2001). To assess the effects in this study's sample, enumerators asked households two questions about how the use of pesticides affected their health or well being during the time or immediately after the time in which they were applying pesticides. Specifically, the questionnaire first asked the farmers: "During or after spraying for pesticides on your farm, did you suffer from any of the following symptoms: headaches, nausea, skin irrigation, digestive discomfort or other problems?" If the respondent answered "yes," a second question was asked: "After beginning to feel poorly, did you take any one of the following actions: 1.) visit a doctor; 2.) go home and recover at home; 3.) take some other explicit action to mitigate the symptom." If the respondent answered affirmatively to *both* of the two questions, it was recorded as a case of *pesticide-generated illness*.

GM Rice Adoption and Pesticide Use

Data from the surveys demonstrate that, as designed, the study is examining producers of GM and non-GM rice that are operating in similar environments. This is important since there might be a question about how the farmers within villages were selected (although, as stated above, by protocol they are supposed to be randomly assigned). In particular, the nature of rice farms, the characteristics of rice producers and the market prices faced by households using GM rice and non-GM rice are nearly identical (Table 4). Descriptive data show that there is no statistical difference between the size of the farm (on average 1.03 hectares per household—1.03 for GM rice households; and 1.04 for non-GM rice households), the mix of rice and other crops (54 percent rice in GM rice households; 58 in non-GM rice households) and the age and education level of the household head (measured as years of educational attainment) for GM rice and non-GM rice producers (rows 1 to 4). The prices paid for pesticides and the price received for their output also did not differ significantly (rows 5 and 6). Although the point estimate of the level of fertilizer used on GM rice (1292 kg/hectare) is lower than that for non-GM rice (1354 kg/hectare), the difference is statistically insignificant.

In contrast, there are large differences between GM rice and non-GM rice production in the use of pesticides (Table 4, rows 8 to 11). GM rice farmers apply pesticide less than one time per season (0.6 times) compared to 3.7 times per season by non-GM rice farmers (a level which is statistically significant). On a per hectare basis, the pesticide use in value terms in non-GM rice production (275 yuan/hectare) is more than six times higher than GM rice (45 yuan/hectare). The quantity in physical terms differs by nearly eight times (3 kg/hectare for GM rice farmers compared to 23.5 kg/hectare for non-GM rice farmers). Because of the reduction of pesticide use, GM rice farmers were able to reduce their labor allocation to pesticide spraying significantly, expending only 1.4 days/hectares for the production of GM rice versus 10.1 days/hectare for non-GM rice. Interestingly, although the pattern of pesticide reduction for those that adopt GM rice is similar to the reductions in the case of those that adopt Bt cotton (that is there is a significant drop in the number of sprayings, the quantity of pesticides uses, the cost of spraying and the labor used in pest control—see Huang et al., 2003), there is one important difference. While Bt cotton producers all continue to apply pesticides to control for a number of non-targeted pest, in the case of 62 percent of the sample GM rice plots, farmers did not apply pesticides at all (that is, their quantity in physical terms; value of expenditure; and time allocated to pesticide spraying was zero).

Multivariate Approach to Estimating Pesticide Demand and Yield Effects (Approach 1— Village Effects)

Because other factors might affect pesticide use when comparing GM rice and non-GM rice producers from sample survey data, multivariate analysis is needed to determine the net impact of the adoption of GM varieties on farm-level pesticide demand. To estimate a demand function for pesticide by China's rice farmers in our sample areas, the following farmer pesticide adoption model is proposed:

(1) *Pesticide Use*= f (*Pest Pressure Perception, Pesticide Price, Producer and Farm Characteristics; Weather Effects; Other Plot-specific Effects; Year Effects; Village Effects; and GM Rice Effects*).

In implementing this model (that has been used elsewhere in the analysis of pesticide demand inside and outside of China—e.g., Pingali and Carlson, 1985; Huang et al., 2003), the data from the survey are used to create variables to use in the empirical estimation of equation (1). The dependent variable for the multivariate analysis in this paper is the quantity of pesticides used per season (although substantively identical results are generated when using either the number of sprayings per season or the value of pesticide use). The pest pressure perception variable is created by asking the farmers about the percentage loss that they believe would have occurred had they not sprayed in non-GM rice. The price of pesticides, included in the analysis as yuan per kilogram, is measured as the unit value price of pesticide purchased by the farmer and is calculated for each household by dividing the value of their pesticide purchases by the quantity that they purchased. To hold constant the producer and farm characteristics, the regression model includes the age (in years) and education (in years of education attained) of the household head, whether or not a household head is a village leader (1 if yes; 0 if no) and the size of the farm (in hectares). Weather effects are controlled for by including a *Natural Disaster Dummy*, which is equal to one if the farmer reported that his/her rice plot was affected by either drought or flood (or some other disaster) during the season. We also control for other plot-specific characteristics, including the size of the plot (measured in hectares) and a subjective measure of each plot's quality, which was solicited by asking each farmer if the plot was "high," "medium" or "poor" quality. Year effects are controlled for by including two year dummies (*2003 and 2004 Year Dummy*) that is equal to one for 2003/2004 and zero for 2002.

Importantly, the net effect of GM rice varieties on pesticide use, the main goal of the analysis, is measured by including a single dummy variable (*GM Rice)* which equals 1 if the farmer used either GM Xianyou-63 or GM II-Youming 86. In an alternative specification (not shown), the use of GM rice is measured by including two GM variety-specific dummy variables (GM Xianyou 63 and GM II-Youming 86) and two non-GM variety dummy variables (conventional Xianyou 63 and II-Youming 86). We do not report the of the regression analysis that uses by variety dummy variables, but, in general, they produce the same results. We do, however, include two interaction variables (GM Rice x 2003 Year Dummy and GM Rice x 2004 Year Dummy) in order to analyze if the effect of GM rice on pesticide use changes over time.

In the version of the regression analysis that is based on equation (1), while pesticide use, pest pressure perception, pesticide price, other plot-specific characteristics and the GM dummy variables are measured at the plot level (and the other control variables are measured at the household level), we control for all unobserved village effects by adding a set of *Village Dummy* variables, one for each of the villages in the sample (with one of the Hubei province villages dropped as the base village). Implicitly when we specify the model this way, we are assuming the GM and non-GM rice farmers were randomly assigned within the village (as intended by the pre-production trial's original design). Because practice may have diverged from theory, the assumption is relaxed below in the next section.

Measuring the Effect of GM Rice on Yields

In addition to the effect of GM rice on pesticide use, we also are interested in understanding the effects on production. The descriptive data in Table 4 (row 12) show that there is a marginal net increase in yields for users of GM rice (6657 kg/hecatare) compared to non-GM rice users (6440 kg/hectare), a gain of 3.3 percent. In the descriptive results, however, the difference is not significant. Because we are aggregating across a large number of households that are producing in large number of preproduction trial villages, there may be other effects that are confounding the difference between GM and non-GM rice.

To measure the net effect of GM rice on yields, we specify a second equation (also from Lichtenberg and Zilberman, 1986; Huang et al., 2003):

(2) *Yields*= f (*Producer and Farm Characteristics; Input Use, including Pesticide Use; Weather Effects; Other Plot-specific Effects; Year Effects; Village Effects; and GM Rice Effects*).

where the specification of equation (2) is the same as equation (1) except for several elements. First, we replace the dependent variable, pesticide use, with yields, which are measured at the plot level (in kilograms/hectare). In addition, we include plot-specific levels of input use as additional control variables. Since it is likely that the coefficient on the pesticide use variable is affected by endogeneity bias when estimating equation (2), instead of actual pesticide use, we use predicted pesticide use. The exclusion of Pest Pressure Perception and Pesticide Price from equation (2) means that we are identifying the effect of pesticide on yields through the inclusion of these two instrumental variables in equation (1). As in equation (1), we include village effects and assume that within villages the GM rice plots were randomly assigned.

GM Rice, Pesticide Use and Yields—the Multivariate Results with Village Effects

The results of the pesticide use equation demonstrate that the model generally performed well in explaining pesticide use (Table 5, column 1). The model has a relatively high explanatory power, with adjusted R-square values that are between 0.42 and 0.52, levels that are reasonable for cross-sectional household data (bottom row). Most of the signs of the estimated coefficients of the control variables (i.e., those variable included in addition to the GM Rice dummy variables) are as expected. For example, when farmers perceive pest pressures are high, they apply higher levels of pesticides, other things equal (column 1, row 2). Likewise, higher pesticide prices lead to lower pesticide use (row 3).

Most importantly, the regression analysis illustrates the importance of GM rice varieties in reducing pesticide use (Table 5, column 1, rows 4 to 6). The negative and highly significant coefficient on the *GM rice* variable means that GM rice farmers sharply reduced pesticide use in 2002 when compared to non-GM rice farmers. Ceteris paribus, GM rice use allowed farmers to reduce pesticide use by 14.43 kilograms per hectare in 2002 (column 1, row 4). Given that the mean pesticide use of non-GM rice producers is 23.5 kilograms per hectare (as seen in Table 4, column 3, row 10), the adoption of GM rice in the first year of the preproduction trials was associated with a 61 percent reduction of pesticide use. When examining the impact of the specific varieties (GM Xianyou 63 and GM II-Yuoming 86—results not shown) in both cases the fall in pesticide use is similar. Interestingly, in subsequent years of the survey (2003 and 2004) there seems to be a slight tendency for GM rice farmers to further reduce their pesticide use (as shown by the negative signs on the interaction terms—rows 5 and 6), although the coefficients are statistically insignificant from zero.

Beyond the pesticide-reducing effects, we also are interested in measuring the effects of GM rice on yields. Because we do not know the precise functional form, we specify the yield equation (equation 2) two ways: a.) in log form (i.e., including the log of yield as the dependent variable in equation 2); and b.) using a damage control functional form, a form suggested by Lichtenberg and Zilberman (1986). The damage control functional form may be more appropriate in our analysis, since it perhaps is more correct to model pesticide use as a way of reducing damage from pests rather than as a way to increase yields directly.

Regardless of the functional form, however, from our analysis that controls for village-level effects, we can show that the adoption of GM rice in the preproduction sample villages increases yields, ceteris paribus (Table 5, rows 4 to 6). When using the log of yields as the dependent variable and controlling for village effects (column 2), the adoption of GM rice increases yields by 9 percent. When using the damage control functional form (column 3), the adoption of GM rice increases yields by 11 percent. The yield gains are statistically consistent across the sample years (2002 to 2004—as seen from the insignificant signs on the interaction terms in rows 5 and 6). Hence, in terms of production, in the preproduction trial villages, when we assume that farmers within villages are randomly selected to cultivate GM rice, there is a win-win outcome in production: GM rice producers not only reduce pesticide use, they also achieve higher yields.

Multivariate Approach to Estimating Pesticide Demand and Yield Effects (Approach 2—Household Effects)

While the results from the preceding analysis suggest that GM rice is a win-win proposition on the production side, such a finding, in part, may arise because the sample selection by the scientists in the preproduction trial villages was not random. For example, despite the appeals of scientists, it could be that because better farmers within the preproduction trial villages were more aggressive in their efforts to be signed up for the program, part of the effect that we are measuring is due to management bias and not because of the effectiveness of GM rice. In order to control for the unobservables that could be affecting the results, in this section we redo the analysis for pesticide demand and rice yields and include a set of household dummy variables for any household in the sample that at some time during the study cultivated at least one plot of GM rice and at least one plot of non-GM rice (henceforth, the household fixed effects model). Specified this way, we are able to purge all household-specific unobservables (and above) and in essence look at the results of the experiment of how much pesticide use and yields differ among two or more plots of same farmer.[1]

According to the results from the household fixed effects models, although the impact of GM rice on pesticide use and yields changes somewhat (when compared to the results reported in Table 5, the results using village fixed effects), in general, the nature of the results are the same (Table 6). The average within household, between plot, effect on pesticide use is -19.81 (column 1, row 2). This means that when a household cultivates both GM rice and non-GM rice, on average, the use of pesticide on the GM rice plots falls by nearly 20 kg/hectare, a reduction of nearly 85 percent. When

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[1] While is the possibility that GM rice plots were systematically placed on plots were different from those that were used for non-GM rice, we were assured by the design of the program that the plots were randomly assigned. To confirm that there is no bias in the selection of plots, we ran a regression of plot characteristics on the GM Rice dummy variable (GM Rice dummy = a0 + a1*$X_{\text{plot characteristics}}$ + e) and

allowing pesticide reduction effects by year, the results show that the reduction in pesticide falls progressively year by year (column 2, rows 2 to 4). In 2004 farmers producing GM rice actually reduced pesticide use by 8.52 kilograms per hectare more than in 2002 (row 4). Since pesticide use rose to 26.93 kilograms per hectare for non-GM rice in 2004, this means that by 2004 GM rice farmers were able to reduce their pesticide use by 86 percent ((14.73+8.52)/26.93). Although we do not know the exact mechanism, the results are consistent with the fact that as farmers have begun to become familiar with GM rice technology, they appear to be learning that they can use less pesticides.

In contrast, the results of the yield equations from the household fixed-effects model differ somewhat from those when only village effects are controlled for. Although the coefficients on the GM rice variables are positive, they are not significantly different from zero (Table 6, columns 3 and 4). Therefore, as seen by the comparisons between the village fixed effects approach and household fixed effects approach, there appears to have been some selection bias when it comes to identifying the effect of GM rice on yields. Importantly, regardless of the approach, GM rice adoption leads to large reductions in pesticide use; yields, at the very least, do not diminish.

Assuming the GM rice would be equally effective across large parts of China (those areas affected by stemborers, in particular), the simultaneous rises in output and reductions of inputs mean that GM rice varieties would lead to absolute rises in productivity. In fact, the potential gains to China's economy could be large. Even after considering general equilibrium effects (e.g., the price of rice would fall when rice

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discovered that the R-square coefficient was less than 0.01 and that none of the coefficients were became more profitable and area expanded), Huang et al. (2004) show that the annual gain to China's economy would be US $4.2 billion if GM rice would be fully adopted in the future.

Health Effects

In the same way that research on Bt cotton adoption showed that the productivity effects of Bt cotton were supplemented by positive health effects (Hossain et al., 2004), according to the analysis based on the survey data, similar effects occur within the sample households. Among the sample farmers, if a sample farmer used all GM varieties (and did not cultivate non-GM rice varieties), there was not one case of the farmer being affected adversely pesticide use in any year of the sample—2002, 2003 or 2004 (Table 7). Of those that used both GM and non-GM plots, the health of 7.7 percent of households in 2002, 10.9 percent of households in 2003 and 8.3 percent of household in 2004 reported being affected adversely by pesticide use; none, however, reported being affected after working on the GM plot. Of those that used only non-GM varieties, the health of 8.3 percent households in 2002, 3 percent in 2003 and 5 percent in 2004 were affected adversely. Although the study did not examine the effect on drinking water quality, interviews of farmers showed that many believe that if pesticide use were reduced due to the adoption of GM rice, the quality of the local sources of drinking water would improve.

Conclusion: The Future of GM Rice in China

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significant.

Although China is still struggling with issues of biosafety and considering the issues of international and domestic acceptance, many competing factors are putting pressures on policy makers to decide whether they should approve commercializing GM rice or not and the results in this study provide evidence that should encourage commercialization. The nation has already invested several billion US dollars in biotechnology research and the development of a stock of GM technologies. Many of the new events have already been through several years of environmental release and pre-production trials. As competitive pressures inside China build in the agricultural sector due to the nation's accession to the World Trade Organization in 2001, and as leaders search for ways to increase rural incomes, there will be a continuing demand by producers for productivity-enhancing technology. The past success in developing technologies and high rates of return suggest that products from China's plant biotechnology industry could be an effective way to both increase competitiveness internationally and increase rural incomes domestically. The analysis in this paper shows that in pre-production trial sites the costs of those farmers that adopt insect-resistant GM rice fall and their yields either rise or at least do not fall. Hence, the paper provides evidence that GM rice does improve productivity significantly. Given that the farmers in the sample are small and relatively poor (the average per capita income of the households in the sample is less than 3 dollars per day), leaders concerned with agricultural productivity and farmer income should be expected to seriously consider commercializing GM rice.

The implications of the commercialization of GM rice, should China decide to so, could far exceed the effect on its own producers and consumer. Paarlberg (2003) suggests that if China were to commercialize a major crop, such as rice, it is possible that it would set off a chain reaction in the world. For example, if China were to commercialize rice, it possibly would clear the way for the extension of GM wheat, maize and other crops inside China. If China proceeded in this direction, this could encourage the large grain producing nations, such as Canada, the US and Australia, to continue to expand their programs in GM wheat and other crops, since China is a likely target for their exports in the future. In addition, the commercialization of rice and other crops may induce other developing countries, such as India or Vietnam, to expand their plant biotechnology programs. On the one hand other developing countries might follow China in an effort to remain competitive. On the other hand, with a clear precedent, other leaders might be willing to adopt GM food crops to increase the income of their farmers as well as to improve their health. It is in this very real sense that the future of GM rice in China may have an important influence on the future of GM crops in the world.

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Table 1. Public research expenditures on agricultural biotechnology in China, 1986 to 2003.

Year	Total [a]	Plant	Rice
	(million yuan, RMB, in real 2003 prices)		
1986	89	51	8
1990	204	118	16
1995	273	157	26
2000	861	450	72
2003	1647	996	195
	(million US dollars)		
2003 (at official exchange rates) [b]	199	120	24
2003 (converted at PPP terms) [c]	953	574	115

[a] Total agricultural biotechnology spending includes spending on animals, plants and microorganisms.

[b] The official RMB-US dollar exchange rate in 2003 was 8.277.

[c] The conversion rate of RMB to the purchasing power parity (PPP) in 2003 is calculated by dividing RMB by the official RMB-US dollar exchange rate (8.277) and multiplying 4.787.

Source: Authors' survey.

Table 2. Distribution of sample counties and villages hosted Bt rice pre-production trials in China.

Year	Number of counties and county names	Number of village and village names
Hubei province (GM Xianyou 63)		
2002	3	4
	Xiantao	Qianqiao
	Jiangxia	Laowuye, Tangtu
	Jingmen	Xinglong
2003	5	7
	Xiantao	Qianqiao
	Jiangxia	Laowuye, Tangtu
	Jingmen	Xinglong
	Xiangyang	Huangci, Jiawan
	Huangpi	Xiangjazui
2004	5	11
	Xiantao	Qianqiao
	Jiangxia	Laowuye, Tangtu, Huashanwu
	Jingmen	Donggou
	Xiangyang	Quanshuiyian, Baiyun, Qinglong, Xuwan
	Xiaochang	Qingshui, Ergong
Fujian (GM II Youming 86)		
2002	Shunchang	Shixi
2003	Shunchang	Shixi
2004	Shunchang	Shixi
2004	Taining	Nanhui
Total	8	17
Hubei	5	15
Fujian	3	2

Note: The total number of counties and villages are less than the sum of the villages from each year because the experiment teams kept some villages for more than one year during the sample period; others were added and others were dropped. The pre-production trials of GM II Youming 86 were also conducted in 4 experiment stations (three experiment stations located in Fujian, and another located in Hubei). Observations from the experiment stations were not included in our sample as the farming operations were not operated by individual households.

Table 3. Sample households and the status as Bt and non-Bt rice farmers, 2002 to 2004

Year	Only Bt rice	Both Bt and Non-Bt	Only non-Bt	Total
2002	11	25	37	73
2003	16	52	36	104
2004	41	42	60	143
Total	68	119	133	320

Data Source: Authors' Survey
Note: In addition to having 119 households that planted both Bt and non-Bt rice during the same year, a number of households that were included in at least two years of the survey (74 households) changed at least one of their plots from Bt to non-Bt during the years of the survey.

Table 4. Summary statistics of GM and non-GM rice producers in pre-production trials in China, 2002-2004.

	All households		GM rice [a]		Non-GM rice	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Farm size (ha)	1.03	0.86	1.04	0.88	1.03	0.84
Rice share in crop area (%)	56	24	54	25	58	24
Age of household head (years)	46.8	10.1	47.5	10.9	46.4	9.6
Household head's education (years)	7.0	2.7	7.0	2.8	7.0	2.7
Rice price (yuan/kg)	0.63	0.12	0.62	0.12	0.63	0.13
Pesticide price (yuan/kg)	15.0	14.5	12.7	15.9	16.3	13.6
Fertilizer use (kg/ha)	1331	548	1292	609	1354	509
Pesticide sprayings (times)	2.61	2.17	0.60	0.97	3.70	1.81
Cost of pesticide (yuan/ha)	192	208	45	87	275	210
Pesticide use (kg/ha)	16.1	18.3	3.0	4.9	23.5	19.0
Pesticide spray labor (days/ha)	6.9	7.8	1.4	3.4	10.1	7.8
Yield (kg/ha)	6541	1355	6688	1234	6457	1414
Number of observations (plots)	584		211		373	

[a] GM rice includes 2 varieties, GM Xianyou 63 and GM II-Youming 86.

Source: Authors' survey.

Table 5. Estimated parameters for effect of GM rice on pesticide use and rice yields using Two-Stage Least Squares and Damage Abatement Control Estimators.

Variables	Amount of pesticide use (kg/ha)	Cobb-Douglas function Log (yield)	Damage control function - Weibull Log (yield)
Intercept	9.52	8.26	8.73
	(1.48)	(38.83)***	(39.31)***
Farmer's perception on yield loss (%)	0.05		
	(1.69)*		
Pesticide price (yuan/kg)	-0.23		
	(3.93)***		
GM rice (yes=1; no=0)	-14.43	0.09	0.11
	(2.69)***	(1.90)*	(2.45)**
2003 year x GM rice	-5.17	-0.03	-0.03
	(0.83)	(0.59)	(1.30)
2004 year x GM rice	-8.87	-0.03	0.03
	(1.50)	(0.53)	(1.09)
Household head age (years)	0.11	0.06	0.05
	(1.50)	(1.35)	(1.17)
Education (years of attainment)	-0.06	0.00	-0.01
	(0.28)	(0.57)	(0.41)
Village leader dummy (leader=1; no=1)	1.19	-0.02	-0.02
	(0.44)	(0.73)	(0.57)
Farm size (ha)	-0.78	0.04	0.04
	(0.55)	(2.59)**	(2.54)**
Natural disaster (affected=1; not affected=0)	8.87	-0.50	-0.50
	(3.61)***	(16.17)***	(16.28)***
Plot size (ha)	5.89	-0.81	-0.79
	(0.12)	(1.06)	(1.05)
Plot soil quality (high quality)	0.33	0.03	0.04
	(0.14)	(1.00)	(1.65)*
Plot soil quality (medium quality)	1.21	0.04	0.03
	(0.46)	(1.58)	(1.01)
Labor (days/ha)		-0.00	-0.00
		(0.08)	(0.12)
Fertilizer (kilograms/ha)		0.04	0.04
		(1.94)**	(1.88)*
Machine (yuan/ha)		-0.00	-0.00
		(0.29)	(0.29)
Other inputs (yuan/ha)		0.01	0.01
		(1.27)	(1.35)
2003 year dummy	1.86	-0.03	-0.03
	(0.79)	(1.20)	(1.30)
2004 year dummy	8.70	0.04	0.04
	(3.48)***	(1.22)	(1.09)
Predicted pesticide use		0.00	
		(0.86)	
Damage control function parameter estimates			
e_0 (pesticide parameter in Weibull model)			0.03
			(1.98)**
e_{bt} (Bt variety parameter in Weibull model)			-0.02
			(1.77)*

R-square	0.52	0.42	0.42
Number of observation	584	584	584

Notes: The figures in the parentheses are t values. The symbols, ***, ** and * denote significance at 1%, 5% and 10%, respectively. The model includes 17 village dummy variables to control for village -specific effects, but the estimated coefficients are not included for brevity.

Table 6. Estimated parameters using a household fixed effects model for estimating effect of GM rice varieties on farmers' pesticide application and yields of households in preproduction trials in China.

	Pesticide use (kg/ha)		Yields (kg/ha) in log	
Variables	Model I	Model II	Model I	Model II
Intercept	26.83	25.03	7.83	7.8
	(12.85)***	(11.48)***	(26.65)***	(26.31)***
GM rice dummy	-19.81	-14.73	0.02	0.06
	(16.20)***	(6.27)***	(1.01)	(1.52)
2003 year x GM rice		-4.86		-0.00
		(1.74)*		(0.10)
2004 year x GM rice		-8.52		-0.04
		(2.89)***		(0.82)
Pesticide price (yuan/kg)	-0.27	-0.26		
	(4.49)***	(4.26)***		
Natural disaster dummy (affected=1)	6.59	7.26	-0.53	-0.53
	(2.27)**	(2.51)**	(11.59)***	(11.48)***
Plot size (ha)	1.33	0.88	-0.00	-0.00
	(0.51)	(0.34)	(0.09)	(0.03)
Plot soil quality (high quality)	-4.11	-3.52	0.02	0.03
	(1.92)*	(1.65)*	(0.74)	(0.80)
Plot soil quality (medium quality)	-3.06	-2.85	0.02	0.03
	(1.39)	(1.32)	(0.73)	(0.78)
2003 year dummy	0.19	1.61	-0.05	-0.05
	(0.14)	(1.01)	(2.30)**	(1.89)*
2004 year dummy	5.84	8.43	0.03	0.04
	(3.02)***	(3.98)***	(0.97)	(1.15)
Labor (log)			0.09	0.09
			(2.02)**	(2.11)**
Fertilizer (log)			0.07	0.06
			(1.60)*	(1.53)
Machine (log)			0.00	0.00
			(0.71)	(0.81)
Other inputs (log)			0.02	0.02
			(2.27)**	(2.33)**
Pesticides (log)			-0.00	0.00
			(0.97)	(0.22)
Household Dummy Variables	Included but not reported			
Number of observations	584	584	584	584

Notes: Parameters in the parentheses are t values. The symbols, ***, ** and * denote significance at 1%, 5% and 10%, respectively. Data are from authors' survey.

Table 7. The effect of GM rice use on the health effects of farmers in sample pre-production village sites in China, 2002 and 2003.

	Planted GM rice *only*	Planted *both* GM and non-GM rice		Planted *non-GM rice only*
		GM plot	Non-GM Plot	
2002	0	0	7.7	8.3
2003	0	0	10.9	3.0
2004	0	0	8.3	5.0

Source: Authors' survey.