EVALUATING ROCKFELLER FOUNDATION RESEARCH ON DROUGHT TOLERANT RICE IN CHINA

by

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ABSTRACT OF THE THESIS

Evaluating Rockefeller Foundation Research on Drought Tolerant Rice in China

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This research utilizes economic surplus model and cost-benefit analysis to investigate the justifiability and profitability of drought tolerant (DT) rice research investments by Rockefeller Foundation together with Chinese Government.

The research focuses on a sample of 160 rice farmers in Guangxi and Zhejiang who were instructed to plant DT rice. Then another 144 amongst them planted both DT rice and Non-DT rice in the same plot. The impacts of DT rice on yield, irrigation, and farmer's income are evaluated using both nonparametric and regression analyses.

Results show that DT rice variety significantly increases the yield while decreasing the irrigation. This allows farmers to minimize cost and maximize their income. The research investment has paid off and consumers benefit more than producers from development of drought-tolerant rice variety.

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LIST OF ACRONYMS

DT	Drought-tolerant
MOA	Ministry of Agriculture
MWR	Ministry of Water and Resource
OLS	Ordinary Least Square
RF	Rockefeller Foundation
CCAP	Center of China Agricultural Policy
CAS	Chinese Academy of Science
SAGC	Shanghai Agrobiological Gene Center
LTA	Long-term average
CS	Consumer surplus
PS	Producer surplus
TS	Total surplus
NARS	National Agricultural Research Services
IRRI	International Rice Research Institute

CHAPTER 1: INTRODUCTION

1.1 General Problem

For many years, plant breeders have recognized the potential benefits of drought tolerance and have undertaken research aimed at identifying and incorporating drought tolerance into high-yielding varieties. Drought-tolerant variety that reduces water use in rice production can benefit farmers not only by directly increasing yield but also by reducing farmers' reliance on costly coping mechanisms. However, the financial support for the drought-tolerant variety research has been limited. There has been an on-going debate about whether it is better to concentrate research resources on the high potential irrigated areas or focus on poor areas. In the background of Green Revolution, beginning in the late 1960s and early 1970s, national research organizations had experienced great pride by raising rice yields from 1-2 tons/ha to 3-5 tons per hectare in extensive irrigated areas across south and southeast Asia (O'Toole, 2004). In the light of these successes in the irrigated sector, enhancing rice production through breeding for rainfed zones was associated with a low probability of success and resulted in low priority for research support (O'Toole, 2004).

In 1998 the Rockefeller Foundation began a multi-year, multi-country program that supports for research and technology transfer of drought-tolerant rice in Asia. A key element of this project has been an investment of several million dollars in national agricultural research services (NARS) in China, India, and Thailand, as well as in the

International Rice Research Institute (IRRI) to help them develop and diffuse drought-tolerant rice (O'Toole, 2004). Since the start of the Rockefeller Foundation's projects on drought tolerance, considerable progress has been made. In China, several drought-tolerant hybrids have been developed and approved by authorities starting in 2007.

1.2 Objectives

The primary objective of this study is to investigation the justifiability and profitability of the Rockefeller Foundation's investment on development of drought tolerant rice in China. The specific objectives are to (a) Estimate the direct economic effects on production, irrigation, and farmer's income. (b) Determine the welfare impacts of drought tolerant rice on society. (c) Investigate the effectiveness of drought-tolerant rice by conducting cost-benefit analyses.

CHAPTER 2: LITERATURE REVIEW

2.1 Drought and Agriculture of China

Agriculture is an economic activity depending on the vagaries of weather. Climate related to natural disasters (droughts, floods, and typhoons) are the principal sources of risk and uncertainty in agriculture (Pandy et al., 2007). When among these natural disasters, drought is the most damaging environmental phenomenon (Felix, 1996).

Rice has been the staple crop in Asia for many thousands of years. China is one of the major rice-growing countries in Asia. About 60% of the population lives on rice in China (Zhu, 2000). As water is uniquely essential to the growth and yield of rice, compared to other food crops, so drought will impose severe loss on rice production especially during the periods of rice transplanting, booting, heading and milking (Ding et al., 2004). Drought is considered the most important abiotic constraint to production (Evenson et al., 1996).

Drought happens frequently in China. Before the 19th century, severe drought covering large areas occurred almost every couple of years (Ding et al., 2004). The toll of severe drought events recorded from 206 BC to AD accounted to 1,056. Twenty-nine drought events of moderate to severe intensity occurred from 1950 to 2004. Drought affected different parts of the country every year during 2000 to 2005 (Ding et al., 2007).

Depending on the season when drought occurs, drought in China can be divided into spring, summer, autumn and winter droughts (Ding et al., 2004). Farmers in southern China heavily suffered from summer and autumn drought (from July to September), which is more prominent in this region and could result substantial damages to crops (Ding et al., 2005).

Yield loss of rice was estimated in drought years varies from 7% to 37% depending on different locations, and that production loss of rice ranges between 9% and 64% with the effect of area loss taken into account (Ding et al., 2004). However, the loss in agricultural output is not the only consequence of drought. Drought produces a complex set of highly differentiated adverse impacts that ripple through many sectors of the economy. Furthermore, drought has been associated with food insecurity, malnutrition, starvation, poverty, disinvestment in human capital, and draining of fiscal resources (Pandy et al., 2007).

The frequency of occurrence and consequent significant economic losses has put the drought issues in the forefront of the policy agenda in China (MWR, 2004). Government of China has put great efforts to reduce impact of drought on rice production and on rice farmers' livelihood. Improvement in irrigation facilities and investment in biological improvement of drought-tolerant rice varieties are two important government strategies in dealing with drought in agriculture (Ding et al., 2004).

In three southern provinces of China (Zhejiang, Hubei, and Guangxi), drought occurs with a probability of 10-30% (Ding et al., 2005). Drought occurs during both the planting and reproductive phases of the growth of the rice plant.

In agriculture, drought stress occurs when the amount of moisture in the soil does not meet the needs of a particular crop. Many farmers' crops worldwide are affected by drought stress to some degree every year, but in some cases agricultural losses due to severe drought can be huge. Agricultural water use accounts for about 70 percent of total consumption, mainly through crop irrigation. Irrigation costs depend heavily upon energy prices and the supply of water, and have been steadily increasing.

2.2 Water shortage & irrigation and rice production

Irrigation is an ancient practice that originated along the Tigris and Euphrates Rivers in what is now Iraq, and spread in ancient times to the desert valley of the Nile River in Egypt, the Indus River in Pakistan, and all the way to China. It is estimated that 40 percent of all crops grown in the world today use irrigation. China is the leading country in the size of irrigated area and in the amount of water used in irrigation.

According to the World Bank forecast, Mainland China has only a per-capita share of 2700 cubic meters water per annum, one quarter of the world's average. Even through the scarcity, 68% of water is distributed to Agriculture sector in 2001 (Ministry of

Water Resource, 2002). But recent year, the rapidly growing industrial sector and an increasingly wealthy urban population demand is beginning to compete with the agricultural sector for water (Crook and Diao, 2000; Wang et al., 2005). Rapid increase of water diversions in the non-agricultural sectors is threatening irrigation in China. If no effective measures are adopted, this crisis may have negative effects on China's food security and on the world grain market (Brown and Halweil, 1998; Brown, 2000).

The rising growth of industrial and urban residents has caused more water allocation to non-agricultural uses. From 1949 to 2004, the share of water use for agricultural irrigation declined from 97 per cent to 65 per cent of total water use. At the same time, the share of industrial water use increased from 2 to 22 per cent; the share of domestic water use increased from 1 to 13 per cent (China Ministry of Water Resources, 2004).

Faced with the declining water availability and soaring water demand, some scholars and policymakers insist some measures should be soon carried out to relieve the stress on water resource. Senior officials from the MWR pointed out that China was fighting for every drop of water, and the water crisis was threatening national grain production. Brown (2000) predicted that falling water tables in China might soon raise food prices everywhere. Nankivell (2004) demonstrated that China was now at a point where critical decisions must be made to resolve water issues. Although some other observers have made more moderate predictions, they also suggest that many agricultural producers will have to forgo irrigation (Crook and Diao, 2000).

Some scientists claimed that improvement of irrigation efficiency through the adoption of water-saving technology is the only choice to achieve this goal (MWR, 2000). While other scientists highlight that the development and introduction of rice hybrids that require less irrigation could be the most efficient way to reduce production costs and the competition for water resources. Drought-tolerant crops are designed to provide greater yield stability in years when crops would otherwise suffer due to drought conditions.

2.3 Drought-tolerant rice research in China

During the past five to seven years a number of institutions in China, India, Thailand and the International Rice Research Institute, Philippines have launched various rice genetic improvement programs to address the loses attributed to current and anticipated water-limited rice culture (O' Toole, 2004).

Among these rice research programs, China are perhaps the most aggressive in Asia as it is pressed by the looming water crisis. In the late 1990s assessments of China's future options for fresh water resources illustrated the dire consequences with regard to water and rice (World Bank, 1997).

In March 2000 an international workshop was held at Hainan Island, China in which researchers from several Chinese institutions and the International Rice Research Institute (IRRI) formally took stock of efforts to genetically modify rice for future water-limited production scenarios and planned collaborative research. Several outcomes from that event are noteworthy.

Facilities to conduct “managed or controlled stress” screening have been constructed in Eastern and Central China, namely Shanghai and Wuhan, respectively as well as field drought screening facilities developed on Hainan Island where temperatures allow winter-spring rice crops to be field screened for drought tolerance thus adding one selection cycle per year to the breeding process.

In 2001 and 2002 the Shanghai Agrocbiological Gene Center-Shanghai Agriculture Academy of Science constructed over 2000 square meters of specialized plastic greenhouses. The facilities installed overhead sprinkler and surface drip irrigation capacity, and a 1.8 meter deep drainage system, as well as establishing air ventilation capacity. Early experience illustrates the importance of managing the “microclimate” over the crop to simulate realistic field level evapotranspiration as well as the soil water status. C. Field screening facilities on Hainan Island allow large scale off-season (winter-spring) field screening for drought tolerance.

Another project leaded by Dr. Shijun Ding, funded by Rockefeller Foundation from

2001 to 2003, investigated economic consequence of rice production and impact of drought risk on farmers' livelihood in rural southern China. Major findings are summarized below:

1) Although drought can occur at different seasons, rice farmers are heavily suffered by summer and autumn droughts, which occurs during July and September; 2) Estimated rice yield loss due to drought is about 7 - 37%, the production loss of rice is about 9 - 64%, the production losses of wheat, cotton, maize and beans are also substantial. Percentage loss in values for all crops at household level is 33%. These indicate that the effect of drought at household level is widespread and can be substantial; 3) Rice farmers cope with drought by various strategies, including spatial diversification, income diversification, cultivation flexibilities, adjustment in agricultural input by reducing chemical use, and changes in consumption, and local communities may have its mechanisms, including land allocation and reallocation within the village, to better cope with drought. In addition, local communities provide forecasting of the timing of rice pests and fertilizing by means of local radio, television, newspaper, which also helps farmers to cope with adverse events, like drought.

Researchers at the National Key Laboratory of Crop Genetic Improvement, Huazhong Agriculture University at Wuhan of China has constructed perhaps the world's first large scale "rainout shelter". This facility assures the control of the water regime to field screen rice for drought tolerance. The structure has an experimental area of

1,800 square meters and incorporates rain sensors to close the double-layer roof, and thus protecting experiments. Unlike rainout shelters for other crop species, this structure incorporates deep soil and ground water table management and drainage (2.0 m deep concrete valved-drains) and surface and sprinkler irrigation facilities to simulate water deficits under large-scale rice cultivation.

Zichao Li and his group from Key Lab of Crop Genomics and Genetic Improvement, Ministry of Agriculture, and Key Lab of Crop Genetic Improvement, China Agricultural University in Beijing, used Double Haploid (DH) population of 118 lines, derived from the cross of upland rice IRAT 109 (Japonica) and Paddy rice Yuefu (Japonica) to anayse correlation between some drought resistant traits and index of drought resistance (IDR) and to detect QTLs in three different cultivation conditions (upland, paddy and root pipt-cultivated). Based on the correlation analysis, they found that root thickness, water potential, osmotic concentration, 1000-grain weight, and percent of seed-setting are significantly correlated with the IDR.

Drought frequently occurs in the late summer or early fall in rice producing areas of central and southern China, hitting the rice crop at late stages of growth and development, which causes significant yield loss. In order to investigate this problem, Qifa Zhnag from National key Laboratory of Crop Genetic Improvement, Huazhong Agriucultural University in Wuhan took a comprehensive approach to study the genetic and molecular bases of drought tolerance in rice emphasizing the late stages of the rice crop, with the goal to improve the cultivars and hybrids. The project included following components: (1) germplasm screening and identification; (2) Genetic analysis and mapping QTLs for drought tolerance, and expression profiling of drought induced breeding.

In the past 20 years, the research efforts in screening and breeding DT germplasm in China have been limited largely because of absence of well established screen facilities in China. In 2001, a “scientific based” field screen facility was set up in the Shanghai Agrobiological Gene Center, funded by the Rockefeller Foundation to Luo Lijun research Group. This facility has a plastic shelter and drainage system for both rainfall and groundwater. A sprinkler irrigation system was installed to ensure water supply. A total of 800 rice germplasm resources identified previously as DT materials were re-evaluated in the water-controlled condition. Forty-six lines showed high-level drought tolerance according to leaf rolling, providing rich resources for genetic improvement of rice. From these lines, 15 DT lines were used as the donor parents in our molecular breeding program for development of introgression lines (ILs). ILs will be used to identify genes/QTLs for DT using DNA markers.

2.4 Rockefeller Foundation (RF)

The Rockefeller Foundation (RF) is a prominent philanthropic organization and private foundation established by the six-generation Rockefeller family. Its central historical mission is "to promote the well-being of mankind throughout the world."

Since its establishment in 1913, the Rockefeller Foundation has sought to identify and then to allocate the financial resource on these areas. The Foundation pioneered the frontier of global philanthropy and continues to find and fund solutions to many of the world's most intractable challenges.

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 more tolerant to both biotic and abiotic stresses (Evenson et al., 1996)

In 1998, the Rockefeller Foundation began put its emphasis on development and dissemination of drought tolerant rice in Asia. Millions of dollars are invested in national agricultural research service (NARS) in China, India, and Thailand, as well as in the International Rice Research Institute (IRRI).

Table 1. DT Rice Breeding Projects Funded by Rockefeller Foundation in China

	Group leader	Organization	Location	Target
1	Dr Luo Lijun	First at CNRRI, now SAGC	Shanghai	Low-land drought resistant and water saving hybrids Conventional breeding – upland & lowland rice
2	Dr Li Zhikang	CAAS / IRRI	Beijing	Higher yield in drought and regular years – whole country Basic research on molecular breeding First target - japonica varieties for north
3	Dr. Zhang Qifa	Huazhong Agricultural Univ.	Wuhan, Hubei Province	Yangtze river basin – yields, DT, water saving Conventional breeding, MAS and Transgenic research

Source: Compiled by the author

2.5 DT rice's secondary advantages

2.51 Water Saving

Water scarcity in China has arisen because of the limited water supply and the increasing water demand. Agricultural sector is the main water-user in China in 2001 (Ministry of Water Resources, 2002). Meanwhile, the rapidly growing industrial sector and an increasingly wealthy urban population demand is beginning to compete with the agricultural sector for water (Crook, 2000; Wang, et al., 2005). However, as oppose to the industrial and residential sectors, the current water pricing policy in China's agricultural sector has not been effective in providing water users with incentives to save water. Furthermore, previous water-saving technologies, such as drip and sprinkler irrigation, have failed. Under these circumstances, planting drought-tolerant rice could be a most effective emerging solution to deal with water saving.

2.52 Stabilize Rice Production and Alleviate Food Insecurity

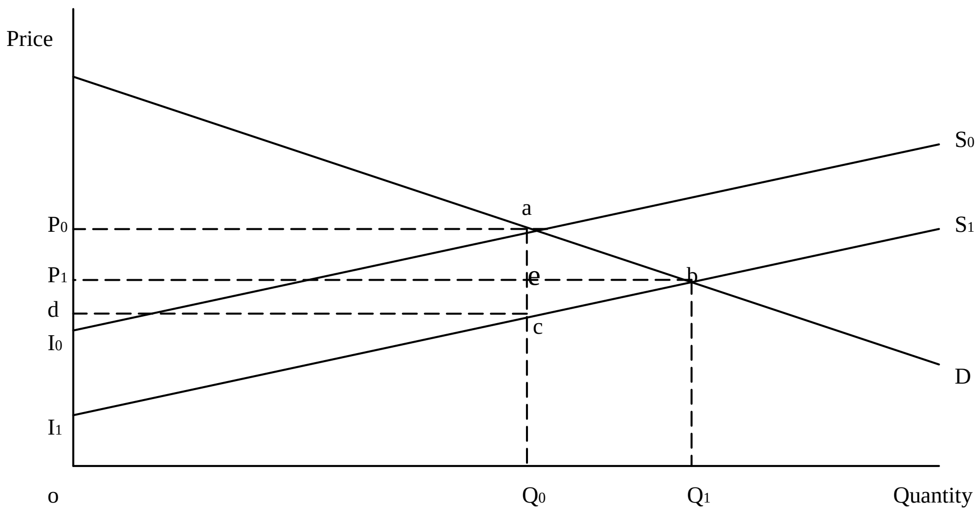
Rice is the staple food for most Asian countries including China, but rice production needs a lot of water. Drought has become the single significant factor limiting rice production in North China and the rainfed areas of South/Southeast Asia. Developing drought tolerant (DT) rice cultivars is considered to be the most efficient way to stabilize rice production and alleviate food insecurity and poverty in China and Asia.

CHAPTER 3: CONCEPTUAL FRAMEWORK

The concept of economic surplus underlies most of the methods used by economists to estimate the benefits and costs of agricultural research. In this study, Economic Surplus Model developed by Alston, Norton & Pardey is applied as analytical framework to do an impact evaluation of Drought-tolerant rice variety's breeding and dissemination in southern China.

3.1 Research-induced Technical Changes in the Market

Figure 1. Surplus distribution due to technology change



Source: Alston, Norton and Pardey (1995)

The model makes the following assumptions:

1. Chinese rice market is a closed economy.

   In China, export of rice accounts only 1.2% of the total production (Huang 2004).

2. Parallel supply shift where the vertical difference between the two curves is

constant.

The basic model of DT research benefits in a closed economy is shown in Figure 1. In this graph, the downward line denoted by D represents the demand for rice. The supply curves of the product before and after DT research-induced technical change are depicted by S_0 and S_1, respectively. The initial equilibrium price and quantity are P_0 and Q_0, and the new equilibrium after the supply shift are P_1 and Q_1.

The change in DT technology leads to a new equilibrium with lower price P_1 and higher quantity Q_1. The consumer surplus increased to the area under the demand curved and above the lower price P_1 and higher quantity Q_1 (area DP_1b), while supplier surplus increases to the area below the new price P1 but above the new supply curve S_1 (area P_1I_1b).

The increased total benefit is equal to the area beneath the demand curve and between the two supply curves ($\triangle TS$=area I_0abI_1). This area is a sum of two parts: (a) the cost saving on the the original quantity (area I_0acI_1) and (b) the economic surplus due to the increment to production and consumption (triangular area abc). Viewed in alternative dimension, the increased total benefit could also be partitioned into benefits to consumers in the form of the change in consumer surplus ($\triangle CS$= area P_0P_1ab) and benefits to producers in the form of the change in producer surplus ($\triangle PS$= area P_1bI_1- area P_0aI_0). Under assumption 2, area dcI1=area P_0aI_0 and the change in producer surplus is equal to the net benefit on current production (area P_1bcd).

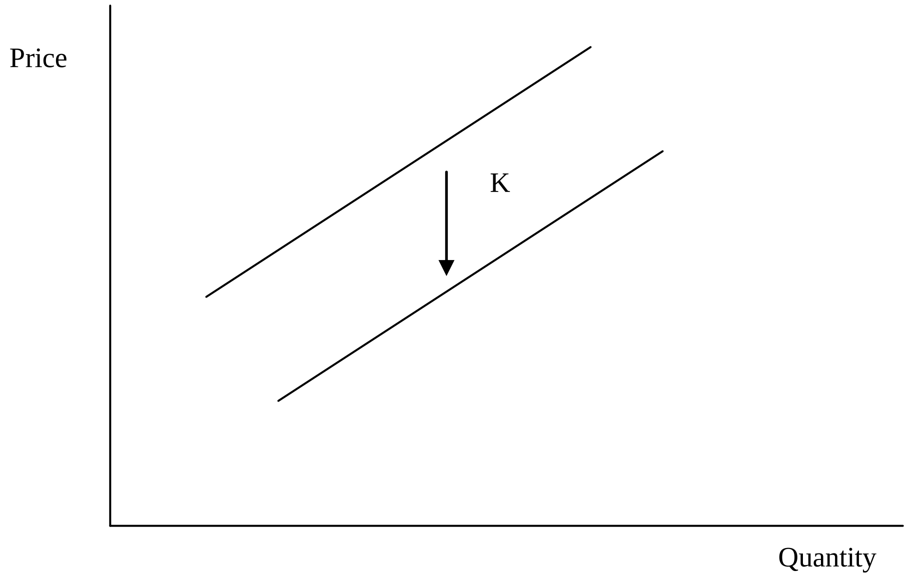
The effects can be expressed algebraically as follows:

$$\Delta CS = P_0 Q_0 Z(1 + 0.5 Z\eta)$$
$$\Delta PS = P_0 Q_0 (K - Z)(1 + 0.5 Z\eta)$$
$$\Delta TS = \Delta CS + \Delta PS = P_0 Q_0 K(1 + 0.5 Z\eta)$$

Where K is the vertical shift of the supply function expressed as a proportion of the initial price. η represents the absolute value of the elasticity of demand and ε indicates the elasticity of the supply shift. Z is calculated by K ε/ (ε+ η).

3.2 Conceptual Issue of Research-induced Supply Shift

Figure 2. Supply shift caused by technology change



Source: Alston, Norton and Pardey (1995)

The size of the research-induced supply shift — the K-factor — is a crucial determinant of the total benefits from research. The accuracy of the estimate of K and its path over time, reflecting adoption lags and so on, will determine the accuracy and validity of the estimates of research benefits and any research priorities that are derived, based on those estimates.

The K-shift is defined as being equal to both (a) the proportionate reduction in average cost of production excluding rent, relative to initial average cost excluding rent, and (b) the proportionate shift down in the equilibrium supply curve, relative to the initial price.

Suppose the following information could be collected for DT rice variety research program:

E(Y) is the expected proportionate yield change per unit of area due to DT technology adoption;

E(C) is the expected proportionate cost change per unit of area due to DT technology adoption;

E(F) is the expected proportionate change in the use of allocatable fixed factors per metric ton of output;

s : quasi-rents to allocatable fixed factors account for a fraction of preresearch costs per metric ton;

r_t : is adoption rate;

δ : depreciation rate;

ε_{s0} : supply elasticity when DT rice is not introduced;

p : probability of successfully leading to a new technology, assumed to be 100% in this paper because DT rice is already produced;

P_0 : equilibrium price before the DT technology-induced supply shift;

P_1 : equilibrium price after the DT technology-induced supply shift.

Given the information on potential yield changes, adoption rates, and so on, values for the absolute reduction in costs per metric ton k, for all future years can be projected as follows.

1. Assuming the use of variable or quasi-fixed inputs does not change in order to bring forth the projected yield increase:

$$k = [E(Y)/\varepsilon]Pr_t(1-\delta)P_1$$

$$K = k / P_0$$

Where we presume P is equal to 1, indicating the probability of successfully leading to a new technology in our study is 100% because the DT rice variety is already produced. r_t is the adoption rate for different years and δ describes depreciation rate in the new technology. P_1 and P_0 are prices after and before the supply shift.

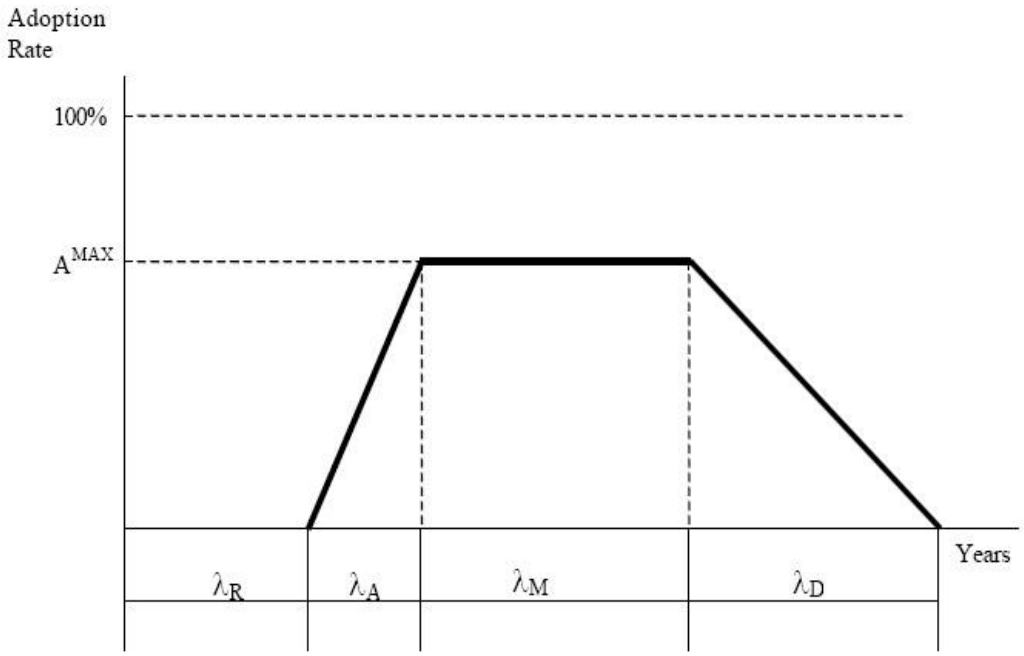
2. Assuming the use of variable or quasi-mixed inputs change

$$k = \left[\frac{E(Y)}{\varepsilon_s} - \frac{E(C)}{1+E(Y)} - sE(F)\right] pr_t(1-\delta)P_1$$

$$K = k / P_0$$

Figure 1 is the basic static model for research evaluation. However, evaluations of the economic effects of research involve procedures to account for the timing of streams of benefits and costs, since there may be lengthy lag times between the initial investment in research, the eventual adoption of research results, and the flow of research benefits.

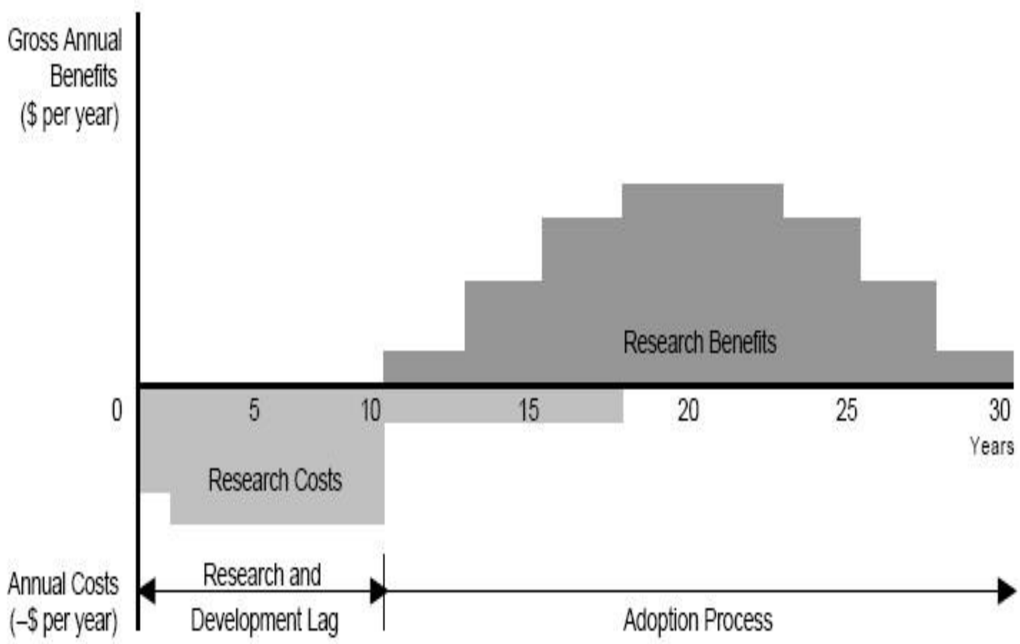
Figure 3. Trapezoidal adoption profile



Source: Alston, Norton and Pardey (1995)

Figure 3 shows the trapezoidal adoption curve and shows how the parameters (λ_R λ_A λ_M λ_D A^{MAX}) above may be used to define the entire curve. The detailed derivation and calculation is illustrated in section 5.3.3 and appendix A5.4 of Science Under Scarcity by Alston et al. (1995).

Figure 4. Net research benefits over time



Source: Alston, Norton and Pardey (1995)

Figure 4 represents schematically the timing of flows of benefits and costs from a successful investment in developing a new technology. The vertical axis represents the flow of benefits and costs in a particular year and the horizontal axis represents years after the commencement of the R&D investment.

Initially, R&D projects involve expenditure without benefits so that, during the research lag period (say 3-10 years), only R&D costs (negative benefits) are considered. After the initial research lag there may be a further delay, a development lag of several years, involving field trials for testing, certification and approval of the new technology or new variety. Even when a commercial product is available, there are further lags before the maximum adoption of the new technology is achieved. The adoption lag may involve several years. Eventually, as shown in Figure 4, the annual flow of net benefits from the adoption of the new technology becomes positive (at least, for a profitable investment this is true). In most cases the flow of benefits will eventually decline as the new technology is progressively abandoned when it becomes obsolete. A complete evaluation of a particular research investment must therefore take account of the dynamic relationships between investments in research that lead (after some lags) to a stream of future benefits as shown in Figure 4.

3.3 Measuring the Research-Induced Supply Shift

According to above formulas, when calculating the shift in supply curve K, we need to know the yield change and cost change after DT rice is adopted. With experimental design method, we could directly use median data. However, in order to get more precise result, we also use simple OLS regression and 2SLS simultaneous equation models to find out the causal relationship of DT rice on yield.

CHAPTER4: SOURCE OF DATA

4.1 Background

The most unique part of this study is the source of data. In none of the previous studies, in China, India and in Thailand, have the researchers had access to the farm field survey data. Previous studies are primarily based on research station data or "mother-baby data. Peng (2007) used the research station data to suggest that Rockefeller Foundation's invest on Drought-tolerant rice is a good investment in China. Two years later, Gautam et al. (2009) prove that DT rice increase social welfare as a whole based on further better data, mother trail data in East Indian. While research station data strictly control for all the physic elements using modern technology, such as humid, temperature, planting method, etc, mother trial data are from farmers' field which is much more similar to the actual growing experience. However, both of these two types of data have fatal limitation in the economic evaluation because the data is from scientists who intend to support their research.

In 2007, Prof. Carl Pray led his Chinese collaborate team, Prof. Luping Li from Center for Chinese Agricultural Policy (CCAP) used experimental design method to get farm field survey data. In order to avoid any influence from research institution cultivating DT rice varieties, they conducted an original, independent and comprehensive experiment.

4.2 Experiment Site Select

This study focuses on southern China. In terms of rice ecological zoning, southern China accounts for 88% of the total rice area and 86% of the total rice production of the country (Zhu, 2000). We choose two provinces and each of them has their own research significance.

For Guangxi, it represents a poorer area, with a low proportion of irrigation and low rice yields. Farmers in Guangxi are relatively poorer and less educated. The overall temperature during the year is 16-22 degree centigrade and the average annual rainfall is 1500mm (Ding, 2004). Although the rainfall is sufficient, there are almost two third of cultivated land are lack of irrigation because irrigation facilities are difficult to build in Guangxi's vary topographies and Karst soil (Ding, 2004). Therefore, most of the agricultural cultivation area is susceptible to drought. The spring drought may cause transplanting delay of rice and the autumn drought may result in yield declining.

As for Zhejiang, it is relative an economically developed and industry aggregate district. Zhejiang lies in southeast China with plenty of water resource and well-established water irrigation facilities where rice production is less affected by drought and water shortage. However, the water demand for industry is constantly increasing, which incurs the tension of water supply. Furthermore, 68% of the household income in Zhejiang's villages is from non-farm sources, indicates that non-farm activities prevail in the Zhejiang's villages (Ding, 2004). If the agricultural water use cannot be saved by production of DT drought, then the water can be put into industry use which will further develop industry and thus increase household income.

4.3 Why Choose Hanyou No.3

The Superiority of the DT rice to the Non-Dt rice is not limit to the genetic difference, but also displays in the field of grain quality and yield. Scientists from SAGC where successfully developed the DT rice hybrid claimed that besides DT rice's high yielding feature, its grain quality is also better than that of Non-Dt rice.

We chose Hanyou No.3 as the representative drought-tolerant variety in our experiment, which was developed by Shanghai Agrobiological Gene Center (SAGC). Why we sort out Hanyou No.3 among these cultivars? Two characteristics of Hanyou No. 3 are taken into account. One is that Hanyou No.3 is partly commercialized by 2007. The seeds could be purchased directly from a seed company other than the research institutions. The other one is that Hanyou No. 3 is hybrid, which will be accepted by farms more easily, because hybrid rice have high yields compared to other type of cultivars.

4.4 Experimental Design

In China, the data of Drought-tolerant rice's cost and returns on farm field was not available no matter from the government or industry. Therefore, a farm level survey is necessary. This study was conducted jointly by the Center for Chinese Agricultural

Policy, Beijing (CCAP) of CAS, Beijing, and the Department of Agricultural, Food, and Resource Economics of Rutgers University. The research is funded by Rockefeller Foundation. We designed and pre-tested the survey questionnaire in August 2008. First round survey was conducted in December 2008 which contained Guangxi province. Gaining experience, improved second round survey was conducted in December 2009, furthermore including Zhejiang province, which runs on importing water out of province because its water resource is not enough for both manufacturing industry use and agricultural use. With a view to guarantee higher data quality, this article uses the data from second round dataset in 2009.

The sample was a stratified random sample. Zhejiang and Guangxi were the only two provinces where Drought-tolerant rice varieties have been approved for commercial use. In Guangxi, Laibin county and Louzhou county were chosen with insufficient irrigation facilities due to the varying topographies and Karst soil. They suffer a lot when drought occurs. The spring drought causes the delay of transplanting and the autumn drought occurs with yield declining. In Zhejiang, Yiwu, the one of the biggest small commodity markets in the world, bestowed with high industrial development, is facing imbalance water use between industry and agriculture. It is a water deficit county and needs to input water form adjacent area. Within the selected villages the farmers were randomly selected and then these farmers were interviewed. The final sample (2009) consisted of 160 households from four counties (eight villages) of Zhejiang and Guangxi provinces, which is depicted in table 2.

Table 2. Fieldwork sites of farm-level survey, 2009

Fieldwork sites	Province	City	County	village	household	Sum
1	Zhejiang	Jinhua	Yiwu	Loujiawu	20	40
				Dongzhu	20	
2	Guangxi	Laibin	Xingbin	Gaoling	20	120
				Tiexiang	20	
	Guangxi	Laibin	Wuxuan	Yubu	20	
				Gencun	20	
	Guangxi	Liuzhou	Liubei	Changtang	20	
				Qingmao	20	

Source: Author's survey

Farmers are required to plant Dt and Non-Dt rice in a same plot to control elements such as soil quality and some farming activities as constant. Meanwhile, another plot was planted with Non-Dt rice. As the incentives, the seed of Han You No. 3 is sent to farmers free. The implementation of experimental design method is shown in figure 5.

Table 3. Sample households and the status of Dt and Non-Dt rice farmers, 2009

Year	Field site	All households	Households who plant Dt & Non-Dt Rice in a plot (**144HH**)	Households who also plant the third plot (**87HH**)
2009	Zhejiang	40	38	11
2009	Guangxi	120	106	76
	Sum	160	144	87

Source: Author's survey

While this dataset is, to our knowledge, unique in China and contains a wealth of information, there are nonetheless several disadvantages that should be noted. The most important are the following:

(1) Given that all information was gathered during one visit only, there may be recall bias for some questions.

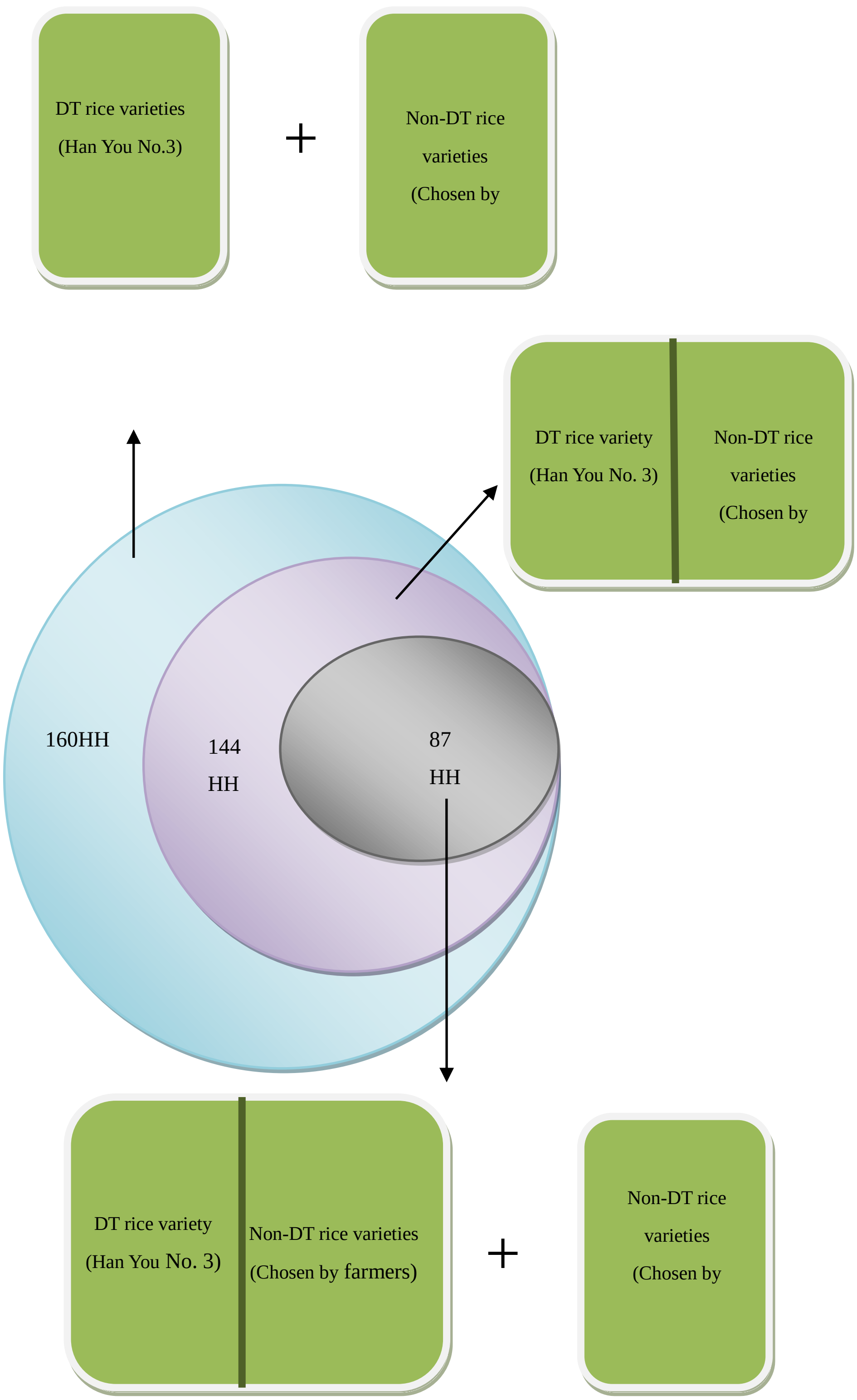
(2) The data are merely a cross-section and aggregate across households within villages. This limits the causal inferences we can responsibly make from the data.

(3) Continuous year-wise data is not available when author work on this paper.

(4) The exact rice quality of Hanyou No. 3 has not been quantified.

(5) There is lack of information about the extent of spread of the Hanyou No.3 rice variety in the survey areas and their spread into other provinces.

Figure 5. Implementation of experimental design method



Source: Author

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Experimental Design Method

The experimental design method that Dt and Non-Dt rice are planted in the same plot, made some major contributing elements constant, such as weather, soil quality, plot's drought feature. Thus, we can compare the mean of all the factors concerning farmers' characteristics, input, farm activities, and yield of DT rice and Non-Dt rice, directly.

Data from whole sample (Table4) demonstrate that, as designed, the study is examining DT and Non-DT rice varieties that are planted in similar environments (table, cols. 1-3). Although, farmers are supposed to be randomly assigned within villages by rule, this is important since there might be a problem during the operation. The descriptive data show that there is no statistical difference between the size of the farm (on average 10.77 mu per household: 10.25 for DT rice and 11.95 for non-DT rice), and the age and education level of the household head (measured ad years of educational attainment) for DT and Non-DT rice producers (rows 1-3). The times of spraying pesticide and herbicide also did not differ significantly (rows 4 and 5). What is more, the difference of hours of labor work conducted per mu between DT rice and Non-DT rice is statistically insignificant, which further verifies that the experimental design of 144 household samples is successfully put into practice.

In contrast, there are large differences between DT rice and Non-DT rice production in the use irrigation (cols. 1-3, row 6). DT rice varieties apply irrigation less than one time per season (1.1 times) compared to 3.2 times per season by Non-DT (a level that is statistically significant). On a per mu basis, the irrigation use in value term in Non-Dt rice production (13.2yuan/mu) nearly doubles which of DT rice production (7.3 yuan/mu). Despite the growing days of DT rice were statistically 2.5days shorter than Non-Dt rice’s, yield of DT rice were 24.8kg/mu higher than those of Non-Dt rice (the results are significant at the 1% level). The fertilizer used (kalium, phosphorus, nitrogen) all differ significantly between DT rice and Non-Dt rice.

Columns 4-6 demonstrate that when a subset of 144 households that produced both DT rice and Non-Dt rice (out of the overall sample of households used) were sampled, the results found compared to entire sample basically remain unchanged except for the fertilizer use (insignificant) because farmers produced DT rice and Non-Dt rice at the same plot during the same season with same treatment. Also, due to more elements controlled, the comparisons of DT rice and Non-Dt rice may be even more meaningful. Interestingly, although there still is a 20kg/mu yield gap (statistically significant at 1% level), the gap is narrower.

Table 4. Whole sample (160HH) of Dt and Non-Dt rice variety in China, 2009

	Entire Sample (160 Households)				Experimental Design Sample (144 Households)			
	Ave. (1)	DT rice (2)	Non-DT (3)	T-test (4)	Ave. (5)	DT rice (6)	Non-DT (7)	T-test (8)
1. Age of household head (years)	49.5 (10.7)	49.6 (10.7)	49.4 (10.6)		49.9 (10.8)	49.94 (10.8)	49.9 (10.8)	
2. HH head's education (years)	7.7 (2.6)	7.6 (2.6)	7.8 (2.6)		7.7 (2.6	7.7 (2.6)	7.7 (2.6)	
3.Farm Size (mu)	10.77 (10.6)	10.25 (10.3)	11.94 (9.79)		10.88 (10.7)	10.88 (10.7)	10.88 (10.7)	
3.Growing days	120.5 (9.0)	119.0 (6.7)	121.5 (10.2)	**	120.4 (9.1)	118.5 (6.7)	122.2 (10.7)	***
4.Herbicide sprayings (times)	1.2 (.47)	1.2 (.48)	1.2 (.46)		1.2 (.48)	1.2 (.48)	1.2 (.49)	
5. Pesticide sprayings (times)	3.8 (1.14)	3.8 (1.17)	3.8 (1.13)		3.8 (1.18)	3.8 (1.18)	3.8 (1.19)	
6. Irrigation (times)	2.7 (2.3)	2.1 (1.8)	3.2 (2.5)	***	2.5 (2.2)	2.0 (1.8)	3.0 (2.5)	***
7. Cost of Irrigation (yuan/mu)	10.9 (22.4)	7.3 (19.8)	13.2 (23.7)	***	9.8 (22.4)	7.2 (20.5)	12.3 (23.9)	*
8. Labor (hour/mu)	30.9 (21.8)	30.5 (23.0)	31.1 (21.0)		30.6 (15.9)	29.5 (16.0)	31.6 (15.9)	
9. Seed use (kg/mu)	1.3 (.49)	1.2 (.46)	1.4 (.50)	***	1.3 (.49)	1.2 (.46)	1.4 (.50)	***
10. Nitrogen (kg/mu)	10.8 (5.1)	10.1 (5.2)	11.2 (5.0)	**	10.7 (5.1)	10.6 (5.2)	10.8 (5.1)	
11. Phosphorus (kg/mu)	4.2 (4.2)	3.9 (2.8)	4.4 (2.6)	*	4.2 (2.9	4.1 (2.9)	4.3 (2.9)	
12. Potassium ((kg/mu)	5.9 (5.9)	5.4 (3.8)	6.2 (3.7	**	5.8 (3.9	5.7 (3.9)	5.8 (3.8)	
13. Pesticide use (g/mu)	935.3 (935.3)	942.2 (402.6)	930.7 (388.3)		961.8 (391.5)	940.5 (399.6)	983.1 (383.4)	
14. Cost of herbicide (yuan/mu)	5.0 (5.0)	5.0 (3.7)	4.9 (3.5)		5.0 (3.5)	4.8 (3.4)	5.1 (3.6)	
15. Yield (kg/mu)	393.7 (393.7)	408.6 (59.5)	383.9 (66.9)	***	394.4 (64.5)	404.4 (58.9)	384.4 (68.5)	***
16. Observations (plots)	403	160	243		288	144	144	

Source. Author
Note: The numbers in the parentheses are the standard deviations. DT rice includes only one varieties: DT Hanyou No.3.

From table 5, we could see that average household age is 53.9 in Zhejiang, which is about 5 years older than that of Guangxi. It is reasonable because in Zhejiang, young labors tend to work at manufacture industry, leaving old people stay at home and take care of farming activities. Farmer's education year of Zhejiang is shorter than Guangxi, because old people have less possibility to get educated than young one.

For Zhejiang, yield of Non-Dt rice is approximately 10 kilograms higher per mu. Some reasons may probably contribute: (1) The growing days for Non-Dt rice are a lot longer (14 days); (2) Fertilizer quantity used on Non-Dt rice (948.4 kg/mu) is larger than DT rice (856.4kg/mu).

Some phenomenon attracted our notice in table 5 is that irrigation cost for Zhejiang province is lower than one twentieth of Guangxi province. In Guangxi province, irrigation cost generated by renting pump, paying electricity fees, or labor fees if needed, etc. While in Zhejiang province, government has built irrigation infrastructure system for farmers already. For the instance in our survey site of Yiwu, small-sized reservoir is built. Every cropping season, the dam of reservoir is open, and water runs down to all the rice area within the village. Farmers only pay small amount of money to local officials according to their plot area per year, so the rice is irrigated systematically and automatically.

Table 5. Experimental design method sample (144 HH) by Location

	Experimental Design Sample (144 Households)							
	Guangxi				Zhejiang			
	Ave. (1)	DT rice (2)	Non-DT rice (3)	T-test (4)	Ave. (5)	DT rice (6)	Non-DT rice (7)	T-test (8)
1. Age of household head (years)	48.4 (10.3)	48.4 (10.3)	48.4 (10.3)		53.9 (11.2)	53.9 (11.3)	53.9 (11.3)	
2. HH head's education (years)	8.2 (2.6)	8.2 (2.6)	8.2 (2.6)		6.4 (2.2)	6.4 (2.2)	6.4 (2.2)	
3.Farm Size (mu)	13.0 (8.1)	13.0 (8.1)	13.0 (8.1)		4.9 (14.3)	4.9 (14.4)	4.9 (14.4)	
3.Growing days	118.6 (6.6)	118.6 (6.6)	118.5 (6.6)		125.4 (12.7)	118.4 (7.2)	132.4 (13.3)	***
4.Herbicide sprayings (times)	1.3 (0.5)	1.3 (0.5)	1.3 (0.5)		1.1 (0.4)	1.1 (0.3)	1.1 (0.4)	
5. Pesticide sprayings (times)	3.5 (0.9)	3.6 (0.9)	3.5 (0.9)		4.5 (1.5)	4.4 (1.6)	4.6 (1.4)	
6. Irrigation (times)	3.0 (2.2)	2.4 (1.7)	3.7 (2.4)	***	0.9 (1.4)	0.7 (1.1)	1.1 (1.7)	
7. Cost of Irrigation (yuan/mu)	13.0 (25.2)	9.6 (23.4)	16.5 (26.6)	**	0.6 (3.0)	0.6 (3.0)	0.6 (3.0)	
8. Labor (hour/mu)	26.4 (13.4)	25.2 (13.5)	27.6 (13.2)		42.1 (16.9)	41.4 (16.6)	42.8 (17.4)	
9. Seed use (kg/mu)	1.5 (0.4)	1.4 (0.35)	1.6 (0.4)	***	0.8 (0.3)	0.7 (0.3)	0.8 (0.4)	*
10. Nitrogen (kg/mu)	11.2 (5.1)	11.0 (5.2)	11.3 (5.0)		9.5 (5.0)	9.3 (5.1)	9.6 (5.1)	
11. Phosphorus (kg/mu)	4.5 (3.1)	4.4 (3.0)	4.6 (3.1)		3.2 (2.1)	3.1 (2.1)	3.2 (2.0)	
12. Potassium ((kg/mu)	6.6 (3.8)	6.5 (3.8)	6.7 (3.8)		3.4 (2.9)	3.4 (2.9)	3.5 (2.9)	
13. Pesticide use (g/mu)	983.1 (377.5)	970.7 (386.9)	995.5 (369.3)		902.4 (425.0)	856.4 (427.1)	948.4 (423.5)	
14. Cost of herbicide (yuan/mu)	5.3 (3.4)	5.1 (3.3)	5.5 (3.6)		4.1 (3.6)	4.0 (3.7)	4.2 (3.7)	
15. Yield (kg/mu)	386.1 (69.7)	401.6 (65.4)	370.7 (70.7)	***	417.3 (39.3)	412.2 (34.5)	422.5 (43.4)	
16. Observations (plots)	212	106	106		76	38	38	

Source: Author's survey

5.2 OLS Regressions to Determine Yield Impacts and Irrigation Demand

Two variables that are used in the following analysis deserve some extra explanation. They both measure the use of irrigation: one is irrigation times during one cropping season and the other one is irrigation cost per mu. As is known, irrigation times and irrigation cost have some correlation and two variables put in the same regression will generate muticollinearity, so we put each one each time we run the regression.

5.21 Approach to estimating yield effects

Because other factors might influence yield when one is comparing DT rice and Non-Dt rice from sample survey data, multivariate analysis is needed to determine the net impact of the adoption of DT varieties on farm-level yield. We are also interested in understanding other effects on yields. The descriptive data in table 4 (cols. 2 and 3, row 14) show that there is a marginal net increase in yields DT rice (408.6 kilograms per mu) compared to non-DT rice adopters (383.9 kilograms per mu), a gain of 6.4%. In the descriptive results, however, there may be other effects that are confounding the difference between DT and non-DT rice. In order to control for the unobservable elements that could be affecting the result, the following model is proposed.

Yields = F (Producer and Farm Characteristics; Input Use, Treatment Effects, DT rice Effects, Provincial Effects)

In this equation, we include provincial effects and assume that within province the farmers were randomly assigned. In order to measure independent variables' effect on production of rice, we use Linear Model.

The results of the table 6 demonstrate that the model generally performed well in explaining production (table 6) in terms of using irrigation cost (col.1) or irrigation times (col.2) as independent variables. Although the model has not a relatively high explanatory power, with adjusted R^2 values that are between 0.1895 and 0.1892, the levels are reasonable for cross-sectional household data (row 14). Most of the signs of the estimated coefficients of the control variables (i.e., those variable included in addition to the DT rice dummy variables) are as expected. For example, the coefficient on growing days variable in the yield equation (col. 1, 2, row 6) shows that more days of rice growing contributed to higher yield.

Most important, the regression analysis illustrates the importance of DT rice variety in increasing output production (table 5, col.1.2, row 2). The positive and highly significant coefficients on the DT rice variable means that DT rice sharply increased yield when compared to Non-Dt rice. Ceteris paribus, Dt rice allowed farmers to enhance production by 28.67 (col. 1, row 1) or 30.10 (col. 1, row 2) kilograms per mu. Given that the mean yield of Non-Dt rice is 383.9 kilograms per mu (as seen in table 6, col.3, row 15), the adoption of Dt rice in in 2009 associated with a 7.8% yield increase.

Table 6. OLS: Yield regression on irrigation cost or Irrigation times (whole sample), 2009

Independent Variable	LM (1)	LM (2)
1. Intercept	129.42 (53.08)	117.72 (54.31)
2. DT rice (yes=1; no=0)	28.67 *** (6.31)	30.10 *** (6.53)
3.Household age (years)	-0.14 (0.34)	-0.11 (0.34)
4. Household education (years of attainment)	-2.76 * (1.43)	-2.82 ** (1.42)
5. Seed (kg/mu)	1.80 (8.25)	1.86 (8.26)
6. Growing days (days)	2.32 *** (0.37)	2.40 *** (0.38)
7. Transplanting (1 = seedling transplanting; 0 = broadcast transplanting)	7.02 (14.08)	7.70 (14.00)
8. Irrigation cost (yuan/mu)	-0.09 (0.15)	-
8. Irrigation times (times/ cropping season)	-	0.80 (1.55)
9. herbicide cost (yuan/mu)	-0.02 (0.91)	0.01 (0.91)
10. fertilizer quantity (kg)	-0.16 * (0.13)	-0.17 * (0.13)
11. pesticide quantity	0.005 (0.008)	0.004 (0.008)
12. Labor (days)	0.14 (0.16)	0.11 (0.16)
13. Provincial dummy (1 = Guangxi; 0= Zhejiang province)	-1.27 (17.41)	-3.17 (17.98)
14. R^2	0.1895	0.1892
15. Observations	403	

Source: Author

Beyond examining yield-increasing effects using whole sample, we also are interested in the difference between Guangxi and Zhejiang province (Table 7). With irrigation cost as one of explanatory variables, Guangxi province displayed highly positive and significant impacts of Dt rice variety on yield. Other factors held constant, Dt rice variety is estimated to increase yield by 30.45 kilograms per mu. As opposed, Zhejiang province displayed neither positive nor significant effects of Dt rice on yield. Besides, the effect of seed used per mu on yield is positive and significant on 5% level in Zhejiang province, which indicates 1kg more seed input leads to 31.63kg/mu higher yield.

Table 7. OLS: Yield regression on irrigation cost by location, 2009

Independent Variable (Use Irrigation cost)	Guangxi (120HH) (1)	Zhejiang (40HH) (2)
1. Intercept	-100.09 (71.08)	350.01 (82.39)
2. DT rice (yes=1; no=0)	30.45 *** (7.19)	-3.30 (11.20)
3.Household age (years)	0.27 (0.39)	-0.57 (0.68)
4. Household education (years of attainment)	-3.73 (1054)	-0.81 (3.37)
5. Seed (kg/mu)	-15.57 (9.26)	31.63 ** (15.16)
6. Growing days (days)	4.09 (0.54)	0.72 (0.52)
7. Transplanting (1 = seedling transplanting; 0 = broadcast transplanting)	4.32 (14.36)	Dropped
8. irrigation cost (yuan/mu)	-0.024 (0.15)	2.50 (1.63)
9. herbicide cost (yuan/mu)	2.13 (1.08)	-0.60 (1.62)
10. fertilizer quantity (kg)	-0.12 (0.14)	0.25 (0.27)
11. pesticide quantity	0.01 (0.01)	-0.017 (0.013)
12. Labor (days)	0.41 (0.31)	-0.013 (0.13)
13. R^2	0.25	0.18
14. Obs.	312	91

Source: Author

When we use irrigation times as explanatory variable instead of irrigation cost and rerun the regression, the results (table 8) do not change very much except that more variables become significant. Interestingly, in Guangxi province, farmers with more years of irrigation will have negative impact on rice production, which also occurred in Zhejiang province, although not that big and significant. We find in table 5, average household education years in Guangxi is 8.2 years, 1.8 years longer than that of Zhejiang (col. 1.4, row 2), which confirms our guess. More educated people have ability to do other work to increase their income other than only putting emphasis on planting rice. In Guangxi, more educated people tend to plant vegetables because it is more expansive than rice, while in Zhejiang, more educated people go in manufacture industry, left least educated people conducting farming activities.

Table 8. OLS: Yield regression on irrigation times by location, 2009

Independent Variable (Use Irrigation cost)	Guangxi (120HH) (1)	Zhejiang (40HH) (2)
1. Intercept	-99.31 (72.51)	336.33 (86.83)
2. DT rice (yes=1; no=0)	30.30 *** (7.42)	-2.14 (11.80)
3.Household age (years)	0.28 (0.39)	-0.40 (0.69)
4. Household education (years of attainment)	-3.76 ** (1.54)	-0.25 (3.39)
5. Seed (kg/mu)	-15.75 * (9.30)	31.38 ** (15.48)
6. Growing days (days)	4.10 *** (0.54)	0.72 (0.54)
7. Transplanting (1 = seedling transplanting; 0 = broadcast transplanting)	4.66 (14.31)	Dropped
8. irrigation times (number of irrigation per cropping season)	-0.22 (1.64)	2.75 ** (4.12)
9. herbicide cost (yuan/mu)	2.13 ** (1.08)	-0.53 (1.70)
10. fertilizer quantity (kg)	-0.13 (0.14)	0.37 (0.28)
11. pesticide quantity	0.014 (0.01)	-0.02 (0.01)
12. Labor (days)	0.40 (0.31)	-0.08 (0.17)
13. R^2	0.25	0.16
14. Obs.	312	91

Source: Author

Another inconsistency between Guangxi and Zhejiang province are the opposite effects of seed use on yield. In Guangxi, holding other variables constant, one kilogram more seed use per mu is estimated to decrease the yield by 15.75 kilograms per mu. In the counterpart of Zhejiang province, when other elements are controlled, one kilogram more seed use per mu will increase the yield by 31.38 kilograms per mu. Given that average seed use of Guangxi province is 1.5 kilograms per mu and the seed use of Zhejiang province is 0.8 kilograms per mu, it indicates that farmers of Guangxi province overused the seed, which results in reduction of yield.

Different from the results drawn from the previous regression using irrigation cost, the coefficient on irrigation times becomes significant on 10% level in Zhejiang province, which means one times more irrigation will increase rice yield by 2.75 kilograms per mu, ceteris paribus. For Guangxi province, growing days and herbicide cost variables are significant on 5% and 10% level respectively. Other factors equal, one more growing days is estimated to increase yield by 4.10 kilograms per mu. However, in Zhejiang the coefficient on growing days variable is small and insignificant, which is explainable by the evidence from table 5. Average growing days for Guangxi province is 118.6 days. However, when it comes to Zhejiang province, it is 125.4 days (7 days longer than Guangxi province).

5.22 Irrigation Impacts

This study relies on data collected from regular year which did not suffer from drought. Compared to the benefits that DT rice varieties may bring on drought year (keep yield stable), DT rice varieties' water-saving performance on regular year are a lot more significant. To estimate a function for irrigation, we specify a second equation.

Irrigation Cost = F (DT Rice Effects; Farm Characteristics; Plot Effects; Irrigation Treatment Effects; Provincial Effects)

The dependent variables for the multivariate analysis in this article are the cost of irrigation per mu and irrigation times, respectively. To hold constant the farmer characteristics, the regression model includes the age (in years) and education (in years of schooling) of the household head. Plot effects are controlled for by including a plot irrigation quality dummy, which is equal to one if the farmer reported that his or her rice plot is easy to be irrigated or to drain, and is equal to zero if this rice plot is prone to drought or flooding. We also control for other plot characteristics, including the distance from farmer's home to the plot.

Importantly, the net effect of DT rice varieties on irrigation cost, the primary goal of the analysis is calculated by including DT dummy variable that equals one if the farmer used Hanyou-3.

In the version of the regression, while irrigation cost, plot characteristics, irrigation characteristics, and the DT dummy variables are measured at the plot level (the other control variables are measured at the household level), we control for all unobserved provincial effects by adding a group of village dummy variables, one for Guangxi province and zero for Zhejiang province. Implicitly, when we specify the model this way, we assume that the DT and Non-Dt rice farmers were randomly assigned within province.

The results presented in table 9 are from two regressions, each with irrigation cost or irrigation times as dependent variable. Both of the regressions reveal the significant role Dt rice play to reduce the use of irrigation. Other elements controlled, Dt rice will decrease irrigation cost by 5.37 yuan/mu, or require almost one time less of irrigation during one cropping season.

Table 9. OLS: Irrigation cost & Irrigation times regression (whole sample), 2009

	Dependent Variable (Use Irrigation cost) (1)	Dependent Variable (Use Irrigation times) (2)
1. Intercept	2.99 (8.87)	3.21 (0.85)
2. DT rice (1 = yes; 0 = no)	-5.37 ** (2.17)	-0.98 *** (0.21)
3. Household age (years)	-0.13 (0.12)	-0.02 ** (0.01)
4. Household education (years of attainment)	1.32 *** (0.49)	-0.02 (0.05)
5. Distance (meters from home to plot)	-0.002 (0.002)	-0.0003 ** (0.0001)
6. Plot feature (1= susceptible to drought or flood, 0= no)	-2.66 (2.23)	-0.35 * (0.21)
7. Provincial dummy (1 = Guangxi; 0 = Zhejiang)	11.00 *** (2.81)	2.16 *** (0.27)
8. R^2	0.11	0.22
9. Obs.	403	403

Source: Author

When we see Dt rice's water-saving effect within individual province (table 10, cols.1.2, row 2), it distributes on Guangxi province and Zhejiang province unevenly. In Guangxi, Dt rice variety reduces irrigation cost by 6.89 yuan/mu, while in Zhejiang, Dt rice variety only decreases irrigation cost by 0.04 yuan/mu, statistically insignificant.

Table 10. OLS: Irrigation cost regression by location, 2009

Dependent Variable (Use Irrigation cost)	Guangxi (120HH) (1)	Zhejiang (40HH) (2)
1. Intercept	17.60 (10.40)	-3.90 (3.77)
2. DT rice (1 = yes; 0 = no)	-6.89 ** (2.79)	-0.04 (0.59)
3. Household age (years)	-0.21 (0.58)	0.04 (0.04)
4. Household education (years of attainment)	1.49 ** (0.58)	0.35 (0.22)
5. Distance (meters from home to plot)	-0.001 (0.002)	-0.0005 (0.0008)
6. Plot feature (1= susceptible to drought or flood, 0= no)	-3.86 (2.83)	1.11 * (0.64)
7. Provincial dummy (1 = Guangxi; 0 = Zhejiang)	0.07	0.06
8. R^2	312	91

Source: Author

Same thing is found in table 11 with irrigation times as dependent variable. Dt rice resulted in reduction of 1 time of irrigation in Guangxi on 1% level, while Dt rice's effect is neither obvious or statistically significant.

Table 11. OLS: Irrigation times regression by location, 2009

Dependent Variable (Use Irrigation times)	Guangxi (120HH) (1)	Zhejiang (40HH) (2)
1. Intercept	5.36 (0.92)	1.81 (2.13)
2. DT rice (1 = yes; 0 = no)	-1.16 *** (0.25)	-0.35 (0.33)
3. Household age (years)	-0.018 (0.013)	-0.03 (0.025)
4. Household education (years of attainment)	-0.03 (0.05)	0.075 (0.13)
5. Distance (meters from home to plot)	-0.0004 ** (0.0002)	0.0009 * (0.0005)
6. Plot feature (1= susceptible to drought or flood, 0= no)	-0.49 * (0.25)	0.33 (0.36)
7. R^2	0.10	0.14
8. Obs.	312	91

Source: Author

5.3 Summary of Outcomes

Yield and irrigation are simultaneous determined. Some elements contribute to irrigation will also influence yield at the same time. Besides previous study with experimental design method and OLS regressions, we should model simultaneously to see how Dt rice minimize cost and maximize the yield.

Table 12. Summary of experimental design outcomes

DT rice's Impact	Experimental Design Method		
	144HH Sample	Guangxi	Zhejiang
Yield	+	+	0
Irrigation cost	-	-	0
Irrigation times	-	-	0

Source: Author

Note: + means difference to Non-Dt rice is positive and significant
- means difference to Non-Dt rice is negative and significant
0 means difference to Non-Dt rice is insignificant

When we use whole experimental design sample, we find positive impact of DT rice on yield, and negative impacts on both irrigation cost and irrigation times. In Guangxi, DT rice increases yield and decreases irrigation cost and irrigation times. In Zhejiang, none of these three effects is significant. No evidence is found that DT rice variety makes any difference on yield, irrigation cost, and irrigation times.

Table 13. Summary of econometric outcomes

DT rice's Impact	OLS Single Equation			2SLS Simultaneous Equation		
	Provincial Dummy	Guangxi	Zhejiang	Provincial Dummy	Guangxi	Zhejiang
Yield	+	+	0	0	0	0
Irrigation cost	-	-	0	-	-	0
Irrigation times	-	-	0	-	-	-

Source: Author

Note: + means difference to Non-Dt rice is positive and significant
- means difference to Non-Dt rice is negative and significant
0 means difference to Non-Dt rice is insignificant

Results from experimental design method are further confirmed by OLS single equation. DT rice's impact on yield becomes insignificant in the 2SLS equation, and it appears that DT rice reduce irrigation times in Zhejiang province.

DT rice's yield performance in Zhejiang province is not surprising because DT rice is supposed to do better in drought year rather than regular year. Another possible reason is that the average growing days for Non-DT rice is longer than Dt rice, which element contributed to higher yield significantly. Also, very little impact of DT rice on saving of irrigation cost although irrigation times was reduced a little bit. Due to the institutional setup in Zhejiang province, local government built up water reservoir for farmers, what farmers need to do is to hand in money to local officials each year, and land is irrigated each time the dam of reservoir open. Farmers only add irrigation time themselves occasionally. However, in Guangxi, farmers control how much they irrigate by pumping water from pool. In that situation, they do save money and times of irrigation to get a yield benefit.

5.4 Farmer Income Impacts

The economic impact of Dt Rice is measured by a combination of changes in cost of production and changes in price of rice due to the introduction of Dt rice varieties. In this study the changes in cost and price per unit area are estimated using the farmer level survey.

The mean yield per mu of DT and Non-DT rice from 144HH sample is shown in column (1) in table 16 below. We also could see the from column (2), compared to Non-Dt rice, Dt rice has less variability of yield. We conducted a T-test and found that Dt variety was statistically different form the Dt variety for whole sample and for

Guangxi province, but it is not significant for Zhejiang province.

Table 14. Yields by variety (144HH), 2009

Variety		144HH sample			
		Mean yield Kg/Mu (1)	Variability of yields (Stan. Dev.) (2)	Number of observation (3)	T-test
Whole sample	DT	404.4	58.9	144	***
	Non-DT	384.4	68.4	144	
Guangxi	DT	401.6	65.4	106	***
	Non-DT	370.7	70.7	106	
Zhejiang	DT	412.2	34.5	38	Not sig.
	Non-DT	422.5	43.4	38	

Source: Author

Table 18 includes data on average per-mu costs and returns and net revenue (or income). Regarding inputs, the seed price of DT rice is 40 yuan/kg, which is the price that we purchased from Dr. Lijun Luo, one of DT rice breeding scientists. And the average seed price of various Non-Dt rice varieties (japonica rice, nonglutinous rice, hybrid rice) planted by farmers is 30 yuan/kg. Seed cost of DT and Non-Dt rice are calculated by multiplying each seed use (kg/mu), which we obtain from farm-level survey, with each seed price. Also, Labor Cost (row 7) is calculated by multiplying the rate of labor fees (5 yuan/hour) with hours of labor spent per mu.

Farmer from the survey reported that DT rice's quality is better than that of Non-Dt rice. In these provinces, given that price of Non-Dt is 2.5 yuan/kg, the price of DT (2.875kg/mu) is 15% higher than Non-DT (personal communication with Dr. Luping

Li from CCAP, 30/4/10), which is used to calculate output revenue (table 18, row 1) in our paper. Similarly, output revenue is the product of price and yield.

According to our experimental design data (table 18, cols. 3 and 4), seed costs were always greater for DT rice varieties compared to Non-Dt varieties. However, this difference was offset by a much greater reduction in expenditures for pesticides, herbicide, fertilizer, irrigation and labor, because Dt rice did not have to spend as much time conducting irrigation. The total cost per mu of producing Dt rice was much less than that for Non-Dt rice. Output revenues for Dt rice were higher than revenues for Non-Dt rice due to higher yields obtained by DT rice and higher price for DT rice. After deducting total production costs from output revenues, it (table 18, row 9) shows that net income from producing DT rice varieties was higher than for Non-Dt varieties.

As shown in (table 18, cols. 5, 6, 7 and 8), we are impressed by the difference of irrigation costs spent by Guangxi and Zhejiang, which is caused by the difference of irrigation infrastructure of these two provinces. Guangxi is mostly mountainous, with rough and rocky terrain, poor irrigation with mostly rainfed land and land with poor irrigation. Zhejiang has a higher proportion of land with good irrigation than Guangxi. Due to the poor irrigation facility, farmers have to rent a pump to get water from pool, which results in higher costs on rental fees, electricity, labor use and running water. However, the good irrigation facilities enable farmers just cost farmers water spending. Therefore, the irrigation cost for Guangxi is more than ten times of Zhejiang.

Table 15. Comparison between Dt rice and Non-Dt rice

	Overall Sample (160HH)		Experimental Design Sample (144HH): Overall		Experimental Design Sample (144HH): by location			
					Guangxi Province (38HH)		Zhejiang Province (106HH)	
	DT rice (1)	Non-Dt rice (2)	DT rice (3)	Non-Dt rice (4)	DT rice (5)	Non-Dt rice (6)	DT rice (7)	Non-Dt rice (8)
1. Revenue	1175	960	1163	961	1155	927	1185	1056
Non-labor Cost								
2.Seed	24.0	21.0	24.0	21.0	28.0	24.0	14.0	12.0
3. Pesticide	43.8	42.6	42.4	44.4	43.8	45.8	38.7	40.3
4.Herbicide	5.0	4.9	4.8	5.1	5.1	5.5	4.0	4.2
5.Fertilizer	138.5	150.1	140.2	151.4	156.0	165.4	96.1	112.2
6.Irrigation	7.3	13.2	7.2	12.3	9.6	16.5	0.6	0.6
Labor Cost								
7.Labor	152.5	155.5	147.5	158.0	126.5	138.0	207.0	214.0
8.Total Cost	371.1	387.3	366.1	392.2	369.0	395.2	360.4	383.3
9. Income	803.9	572.7	796.9	568.8	786.0	531.8	824.6	672.7

Source: Author

5.5 Welfare Impacts: Economic Surplus Model

There are mainly two data sources used in following calculation. One is Han You No.3’s national drought resistance trial in year 2005 and 2006 (table 19), which is farm level experimental data (Peng, 2007). The other one is from farm level survey data conducted by author in 2009 described detailed in previous chapter. The farm level survey will lasts for a few years, with purpose to collect data both on drought year and non-drought year. However, till now, the data has been collected and cleared on 2009 is from non-drought year. Since the yield data of drought year is not available right now, we get the yield data of drought year from farm-level tests for drought tolerant rice varieties which is authorized by Chinese Ministry of Agriculture. There are more than one drought tolerant rice varieties, thus we select Han You No.3 as the representative drought variety in this paper, which was produced by Shanghai Agrobiological Gene Center (SAGC). The target areas are two provinces: Guangxi and Zhejiang.

Table 16. SAGC Drought Tolerant rice variety test results

2005 National Trials	
Variety	Yield (kg/mud)
Han You No.3	404.80
Non-DT rice	329.85

Source: SAGC.

Note: These trials were conducted under drought conditions in a number of provinces which represent the drought prone areas in China. 1 ha = 15 mu.

Data needed in this paper includes:

ε: rice supply elasticity within the Chinese market;

η: rice demand elasticity within the Chinese market (absolute value);

P_0: prevailing rice price before the commercial adoption of drought tolerant rice variety;

Y_d: average estimated yield of drought tolerant rice variety (Han You 3) under drought condition in 2005 national trials;

Y_d': average estimated yield of non-drought tolerant rice varieties under drought condition in 2005 national trials;

Y_{nd}: average estimated yield of drought tolerant rice variety (Han You 3) under normal weather in 2009 farm level survey;

Y_{nd}': average estimated yield of non-drought tolerant rice varieties under normal weather in 2009 farm level survey;

R: probability of drought;

r: adoption rate of drought tolerant variety;

P_r: percentage of drought area;

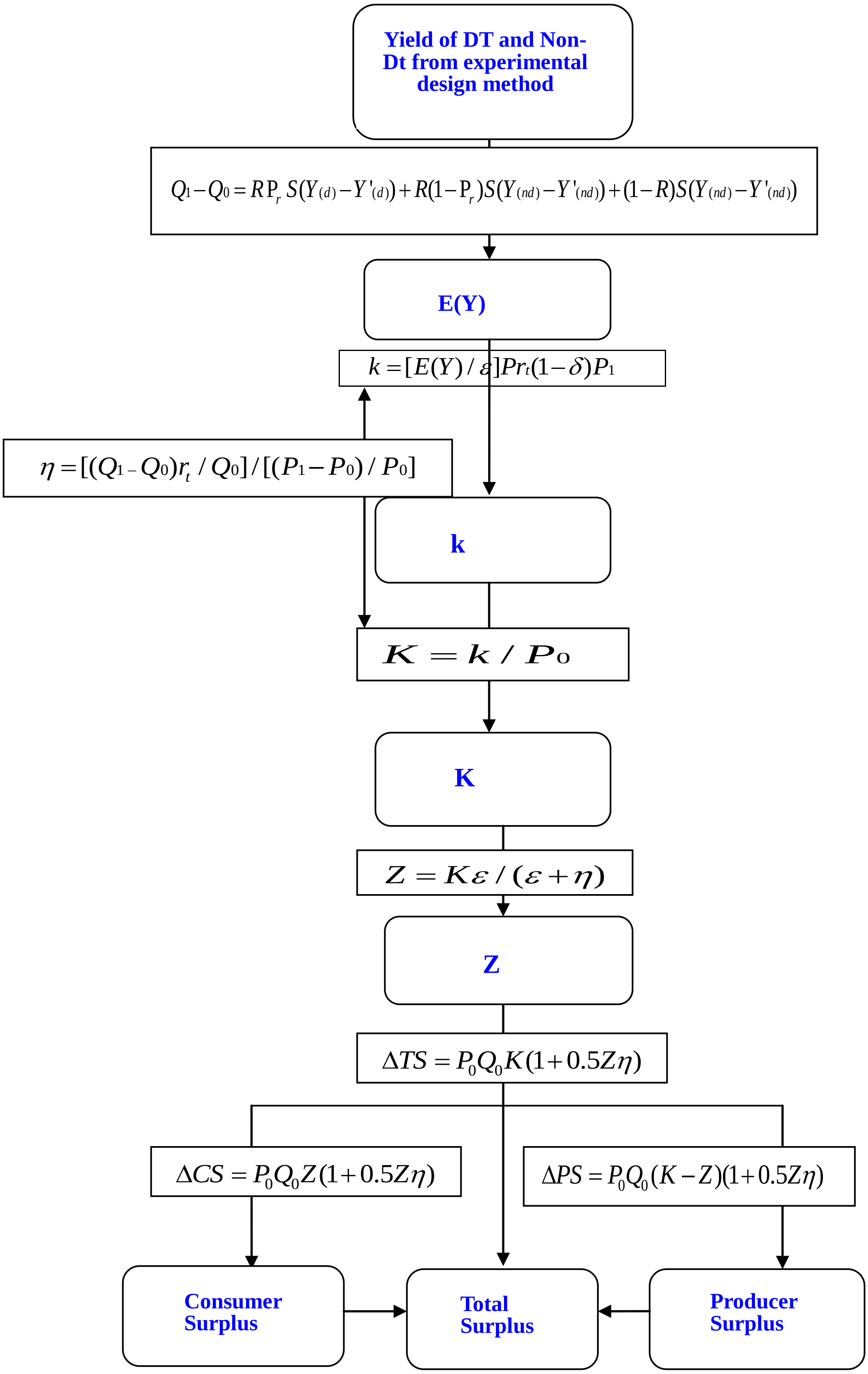
S: rice cultivation;

Pr: percentage of drought area;

Q_0: initial rice production before DT rice is adopted;

Q_1: estimated rice production with DT rice fully adopted.

Figure 6. Stream to calculate economic surplus



Source: author

First of all, we need to get the aggregate production change by checking the differences between DT rice variety and Non-Dt rice variety. 144 households from our surveyed samples were required to plant DT and Non-DT rice variety in a same plot with almost the same farming activities. So, we can examine the differences by comparing the average yield per unit of mu under normal weather and use the yield data from national drought resistance trial in year 2005 and 2006 under drought condition. Then we scale up these differences in a larger geographical area in a particular period with drought probability and percentage of drought area accounted. The aggregate production change with DT rice variety fully adopted is calculated as following:

$$Q_1 - Q_0 = R\,\mathrm{P}_r\,S(Y_{(d)} - Y'_{(d)}) + R(1-\mathrm{P}_r)S(Y_{(nd)} - Y'_{(nd)}) + (1-R)S(Y_{(nd)} - Y'_{(nd)})$$

$$E(Y) = (Q_1 - Q_0)/Q_0$$

where Y (d)-Y' (d) measures the yield difference between DT and non-DT varieties under drought, and Y (nd)-Y' (nd) measures the yield difference between DT and non-DT varieties under normal weather. Where PrS is the drought area at a certain year, and (1-Pr)S is the area not affected by drought at that year. Thus PrS(Y (d) - Y' (d)) is the total production change under drought in a certain geographical area (province) at that year with the DT rice fully adopted, while RPrS (Y (d) - Y' (d)) calculates the total production change for the area affected by drought in drought period. R (1-Pr)S(Y (nd) - Y' (nd)) calculates the total production change for the area not affected by drought in drought period, and (1-R)S (Y (nd) - Y' (nd)) calculates the total production change in non-drought period

Table 17. Data needed to calculate economic E(Y)

Col.	Iterms	Unit	Guangxi	Zhejiang
1	R	(%)	15	10
2	$r_{(max)}$	(%)	10.51	10.15
3	$r_{(min)}$ Pr	(%)	5.39	2.36
4	Yd	(kg/Mu)	404.8	404.8
5	Yd'	(kg/Mu)	329.85	329.85
6	Ynd	(kg/Mu)	404.4	404.4
7	Ynd'	(kg/Mu)	384.4	384.4
8	η		0.28	0.28
9	ε		0.45	0.45
10	P0	(yuan/kg)	2.5	2.5
11	Q0	(10^4 tons $=10^7$kg)	1107.6	660.4
12	S	Mu	31788000	14062500

Source: col.1: Ding et al. (2005)
col.2: China Statistical Yearbook
col.4 - col.5: SAGC
col.6 - col.7: author's survey
col.11 – col.12: China Statistical Yearbook 2009

According to our survey, initial price P_0 is 2.5 yuan/kg, prevailing in 2009 in China. Although price may vary among different location and time, it fluctuates around 2.5 yuan/kg. The initial production Q_0 is from the 2009 China Statistical Yearbook. The definition of Probability of drought R is from Ding et al. (2005): a meteorological drought is considered to have occurred in a particular year if rainfall deficit form LTA (long-term average) during the main rice growing season is 20% or more. Also, Ding et al. (2005) calculates the probability of drought for Zhejiang, Guangxi provinces (table 21). Because the rice planted in our survey is supposed to be affected mainly by summer-autumn drought, drought probabilities used in this paper are for summer-autumn drought.

Table 18. Probability of seasonal drought (R) in southern China, 1982-2001

Province	Spring	Summer	Autumn	summer-Autumn
Guangxi	0.15	0.30	0.25	0.15
Zhejiang	0.25	0.15	0.30	0.10

Source: Ding et al. (2005)

Rice area S is from the 2009 China Statistical Yearbook. For Zhejiang and Guangxi, percentage of drought area (Pr) is calculated with the method of dividing drought covered area by rice sown area, which can be seen in table. Then we take the average of the historical data for 11 years (1996-2006). The Adoption rates for Guangxi (15%) and Zhejiang (10%) used in this paper from Peng (2006) is the highest percentages of drought area among the historical data (1996-2006). He said farmers are believed to adopt DT rice varieties based on the historical climate and the experience they had before. That is to say, farmers in the areas where drought happened in the past are inclined to adopting drought tolerant rice. He claims that the largest percentage of drought area in the past would be the potential that the drought tolerant rice varieties will cover. So he used the highest percentages of drought area (1996-2006) as limit of adoption rates.

Table 19. Percentage of drought area (1996-2006)

	Guangxi	Zhejiang
(r) Highest pct. (%)	10.51	10.15
(Pr) Average pct. (%)	5.39	2.36

Source: China Statistical Yearbook 1996-2006.

Assumptions:

1. Chinese economy of rice production is "closed", since the export of rice is only 1.2% (Huang 2004). In a closed economy, output prices are determined by the interaction between domestic supply and demand curves (Heisey & Morris, 2006).

2. Drought tolerant variety performs the same under different geographical environments; No matter which province is it in.

For the purpose of assessing DT rice research in China, comparison between the change of aggregate economic surplus caused by drought tolerant rice adoption and research investment illustrates how well the new DT varieties benefit the society. According to Peng (2007), Rockefeller Foundation's investment and Chinese government's investment are two main financial resources. Starting in 2001, Rockefeller has invested $770,000 US dollars on this project. And Chinese government has put $150,000 US dollars each year since 2001 till 2007.

Table 20. Data calculated step by step

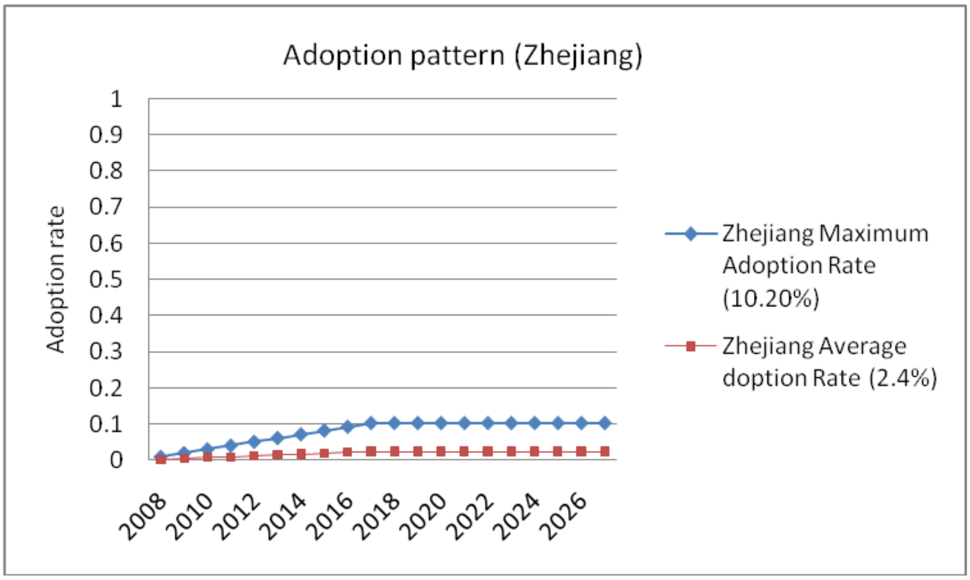
	Guangxi	Zhejiang
Q1 - Q0	649900000	283100000
E(Y)	0.059	0.043
P1	2.3	2.3
k	0.0165	0.0052
K	0.0066	0.0021
Z	0.0040	0.0013

Source: Author

5.4 Simulation of Adoption Patterns

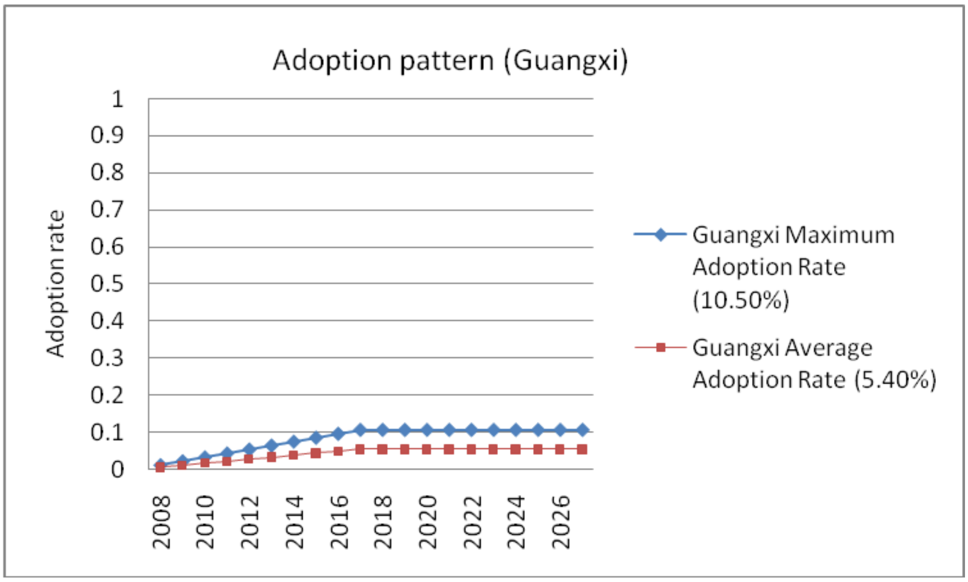
There are two scenarios for each province. The first scenario assumes the adoption rate (r) is historical highest percentage of drought area. The second scenario assumes r is the historical average percentage of drought area (table 22). In our study, it is assumed that year 2008 is the start year of being adopted by farmers in the field because it is the year just after DT rice was approved for commercial use. It has been 7 years (λ_R =7) that between the adoption of new technology (2008) and the time after the initial investment (2001), which is split into research lag (assumed 4 years) and development lag (assumed 3 years). Peng (2007) assumes that the adoption lag is 6 years (λ_A =6) between the release of the agricultural technology and maximum adoption by producers, which is too optimistic because right now scientists are still working through seed production problem of DT rice. In our paper, we assume that adoption lag is 10 years (λ_A =10). With the quick development of technology, the economic life of new variety is shortened. The average economic life of rice variety in 1960s was 12 to 13 years (Ding, 1993). Therefore, we assume technology depreciation rate (δ) is 0 for the first ten years and 5 percentage points higher than previous year starting from the 11th year.

Figure 7. Adoption pattern for DT rice in Zhejiang province



Source: Author

Figure 8. Adoption pattern for DT rice in Guangxi province



Source: Author

The spreadsheets (table 24, 25, 26, 27) are laid out to illustrate the computation of research benefits in a closed economy. Furthermore, they illustrate how the benefits are split up for both consumer and producer for Guangxi province and Zhejiang province with both higher and lower adoption scenarios. Drought tolerant rice variety does induce right shift of supply curve because of its higher yield under both drought and regular climate. Although the shift brings benefits for both consumers and producers, the consumers enjoy more benefits than producers. From 2008, consumer surplus, producer surplus and total surplus as well soar up rapidly, until reach the peak of 2017. After 2017, the benefits start to go down gradually.

5.6 Benefit-cost Analysis

We use economic surplus model to derive annual flows of research benefits and costs. Based on that, cost-benefit analysis method is used to evaluate investment by calculating the anticipated costs and benefits on an annual basis and summarizing as either an anticipated net present value (NPV) or an internal rate of return (IRR). NPV is often used to measure the contributions of research programs to the efficiency objective. IRR is the rate of return that would make the present value of benefits equal to the present value of costs, which ranks programs in terms of their profitability.

Table 21. Cost benefit analysis on DT Rice adoption USD (1USD = 6.64CNY)

	Investment		Benefit		Net Benefit	
Year	RF	Chinese Govern.	Higher adpt. Scenario	Lower adpt. Scenario	Higher adpt. Scenario	Lower adpt. Senario
2001	-80,000	-150,000	0	0	-230,000	-230,000
2002	-80,000	-150,000	0	0	-230,000	-230,000
2003	-80,000	-150,000	0	0	-230,000	-230,000
2004	-180,000	-150,000	0	0	-330,000	-330,000
2005	-150,000	-150,000	0	0	-300,000	-300,000
2006	-100,000	-150,000	0	0	-250,000	-250,000
2007	-100,000	-150,000	0	0	-250,000	-250,000
2008	0	0	9,231,928	3,792,675	9,231,928	3,792,675
2009	0	0	18,448,795	7,605,422	18,448,795	7,605,422
2010	0	0	27,665,663	11,400,602	27,665,663	11,400,602
2011	0	0	36,912,651	15,195,783	36,912,651	15,195,783
2012	0	0	46,144,578	19,006,024	46,144,578	19,006,024
2013	0	0	55,466,867	22,846,386	55,466,867	22,846,386
2014	0	0	64,457,831	26,656,627	64,457,831	26,656,627
2015	0	0	73,795,181	30,466,867	73,795,181	30,466,867
2016	0	0	82,981,928	34,277,108	82,981,928	34,277,108
2017	0	0	92,319,277	38,072,289	92,319,277	38,072,289
2018	0	0	87,650,602	36,174,699	87,650,602	36,174,699
2019	0	0	82,981,928	34,277,108	82,981,928	34,277,108
2020	0	0	78,463,855	32,364,458	78,463,855	32,364,458
2021	0	0	73,795,181	30,466,867	73,795,181	30,466,867
2022	0	0	69,277,108	28,554,217	69,277,108	28,554,217
2023	0	0	64,457,831	26,656,627	64,457,831	26,656,627
2024	0	0	60,060,241	24,743,976	60,060,241	24,743,976
2025	0	0	55,466,867	22,846,386	55,466,867	22,846,386
2026	0	0	50,888,554	20,948,795	50,888,554	20,948,795
2027	0	0	46,144,578	19,006,024	46,144,578	19,006,024

Source: Author

In order to see the whole picture of the research impact, Guangxi and Zhejiang province are put together to compare with the investment. The benefits reach peak point at year 2017 both for higher and lower adoption scenario, before it declines due to the impact of depreciation of technology.

Table 22. NPVs and IRRs based on different scenario

Adoption Rate	NPV	IRR
Higher adpt. Senario (Maximum adoption rate = highest drought area %)	512,744,408	87.93%
Lower adpt. Senario (Maximum adoption rate = average drought area %)	210,586,030	68.79%
Third adpt. Senario (Maximum adoption rate = half of average drought area %)	128,569,301	43.68%

Source: Author

We use the spreadsheet approach by Alston, Norton & Pardey for calculating the net present value (NPV) and internal rate of return (IRR) for the research to evaluate the DT research in China. In our study, we assume the technology will be obsolete in 20 years.

NPV for the research that developed the DT rice varieties is calculated using the following formula:

$$\sum_{j=2001}^{2017} \frac{(\Delta TS - \mathrm{Re}\, searchCost)_j}{(i+r)^j}$$

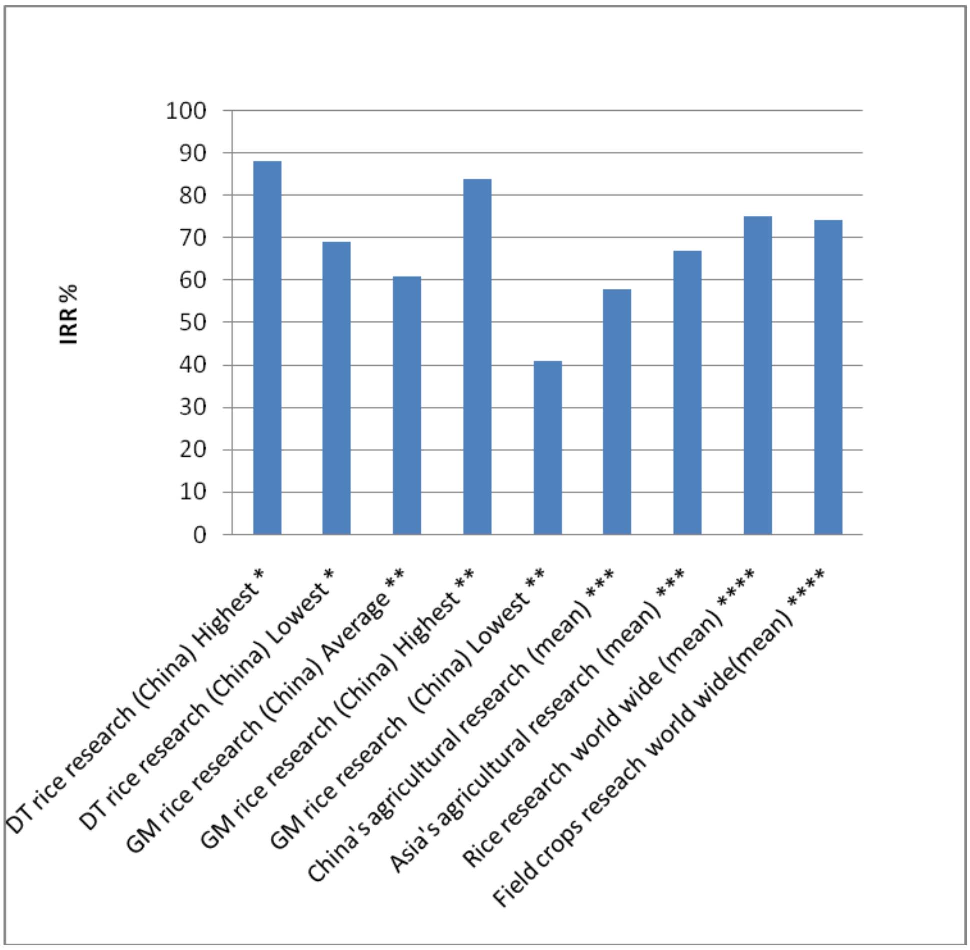
where r is the discount rate (5% in our study).

IRR is computed as the discount rate that would result in a value of zero for the NPV.

$$\sum_{j=2001}^{2017} \frac{(\Delta TS - \mathrm{Re}\, searchCost)_j}{(i+r)^j} = 0$$

The results from table 29 shows apparently that higher adoption brings higher NPV and IRR than lower adoption. The NPVs in both scenarios are positive, indicating that the project is profitable and the research being done in China is beneficial. The IRRs of this research are quite attractive also. Compared with the benefit, the investment is really small. The project is successful and the investments made by RF in the research effort in China have a positive impact.

Figure 9. IRR comparison in agriculture research



* From Table 29.

** Guo (2004).

*** Huang, Hu, Rozelle (2003).

**** Mclntyre et al. (2009).

Table 23. Sensitivity Analysis on IRRs

Adoption Rate	IRR
Higher adpt. Senario (Maximum adoption rate = highest drought area %)	82.54%
Lower adpt. Senario (Maximum adoption rate = average drought area %)	61.21%
Third adpt. Senario (Maximum adoption rate = half of average drought area %)	38.96%

Source: Author’s calculation under dounbled cost compared to Table 30.

CHAPTER 6: CONCLUSIONS

The purpose of this thesis has been made to evaluate the potential impact of Rockefeller's drought-tolerant rice research to find out whether national governments or donors should continue to fund drought-tolerance rice research. This study clearly shows that the research is beneficial by evaluating DT rice's impacts on aspects of production, irrigation, farmer's income and economic welfare of society as a whole.

Major findings of the research include:

1. Experimental design for farm-level field survey is successfully carried out. 144 households out of 160 households planted Dt rice and Non-Dt rice in a same plot strictly following instructions that apply herbicide, pesticide, and fertilizer evenly and simultaneously. The econometric analysis (OLS regressions and SEM model) drew from 160HH sample of 2009, a normal year, are consistent with findings from experimental design method on 144HH sample that the adoption of DT rice variety allow farmers to achieve higher yield and to consume less irrigation.

2. Due to drought-tolerant rice's water saving feature, farmers planting DT rice could save their time and spending on irrigation. Water resource's distribution on agriculture will be reduced. For Zhejiang's case, with an increased demand for water to develop manufacture industry and limited water supply, Zhejiang imported water from other province at high price. With the adopting of DT

rice, the amount of water saved in agriculture sector could be used to support industry development. In return, manufacture industry's development increased farmers' non-farm income. For Guangxi's case, Most of farmers of Guangxi are poor, the save on irrigation may help them to increase income and be out of poverty. However, the meaning is not limit to this, the true value of water in China is much greater than the price of agriculture water use. The saving for the sustainable development of Chinese society is substantially very significant.

3. DT Rice enhances farmer's income by increasing revenue and decreasing cost simultaneously. Furthermore, farmers reported the quality of DT is better than Non-DT, which could not evaluated by economic gain in a short term. Although absolute value of DT rice's income impact on Guangxi province (786 yuan) are smaller than which of Zhejiang province (824.6 yuan), the income difference between planting Dt rice and Non-Dt rice is greater for Guangxi (254.2 yuan) when compared to Zhejiang (151.9 yuan). In Guangxi, farmer's income is primarily from agricultural activities, while farmer's income is mainly form manufacture industry activities for Zhejiang. Therefore, DT rice plays an indispensable role in reducing poverty in Guangxi.

4. Economic Surplus Model applied in our paper manifests that consumer, producers and whole society all benefit from the DT rice variety. Consumers

enjoy more benefits than farmers by paying lower price and buying more rice, however, producers just benefit from yield increase.

5. Cost-Benefit analysis reveals that the welfare DT rice bring highly surpasses the investments spent by RF and Chinese government to develop DT rice. No matter IRR (87.93%) for high adoption scenario or IRR (68.79%) for low adoption scenario are indicating that the research being done in China is effective and the project is worth investing.

Implications

One of the major hurdles in enjoying the benefits brought by development of DT variety is that DT rice variety has not spread as wide as we expected. One of the contributing reasons for this phenomenon is the stagnant regulatory procedures for approving drought tolerant varieties. In China, only Zhejiang province, Guangxi province, and Shanghai have approved DT rice variety for commercial use so far. The problems of obtaining approval for DT rice have incurred the slow spread of DT rice, and also restrict DT rice research in the public and private sectors. Another reason is that both public and private sectors seed producers have not been very interested in DT seed as a result of limited farmer demand, small market size and production problems for hybrid rice in China. Government agencies need to play an active role in facilitating DT rice varieties to get commercial approval. Measures need to be carried out to bring public and private seed companies into full play to the marketing and sale of drought tolerant rice seed.

REFERENCE

Alston, J.M., Norton, G.W., and Pardey, P.G. 1995. “Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting.” *Cornell University Press*, Ithaca and London, pp: 207-440.

Mclntyre, B., Herren, H., Wakhuangu, J. and Watson, R. 2009. “Global Report of IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development): Agricultue at a Crossroads.” *Island Press*, Washington D.C

Brown, L. R. and Halweil, B. 1998. “China’s Water Shortage Could Shake World Grain Markets.” Worldwatch Institute, Washington D.C

Brown, L.R. 2000. “Falling Water Tables in China May Soon Raise Prices Everywhere.” Available from http://www.qmw.ac.uk/~ugte133/courses/environs/cuttings/water/china.pdf.

Crook, F. and Diao, X. 2000. “Water Pressure in China: Growth Strains Resources.” *Agricultural Outlook*, January–February, Economic Research Service, US Department of Agriculture, pp: 25–9.

Ding, S., Pandey, S., Chen, C., and Bhandari, H.N. 2005. “Drought and Farmers’ Coping Strategies in Poverty-afflicted Rural China.” Unpublished report, Rockefeller Foundation, New York.http://66.102.1.104/scholar?hl=en&lr=&q=cache:Dbid_Q1UK-cJ:www.sed.manchester.ac.uk/idpm/research/events/february2005/documents/Ding.doc+Drought+and+farmers%E2%80%99+coping+strategies+in+poverty-afflicted+rural+China

Evenson, R.E., Dey, M.M., and Hossain, M. 1996. “Rice Research Priorities: An Application.” In Evenson, R.E., Herdt, R.W., and Hossain, M. (eds) *Rice Research in Asia: Progress and Priorities,* CAB International, Wallingford, UK, pp: 347-391

Felix, N.K. 1996. “Global Drought Watch from Space.” *Bulletin of the American Meteorological Society*, 78:621-636.

Gautam, R.K., Singh, R.K., and Qadar, A. 2009. “Incorporating Salt Tolerance in Rice with More Precision-status and Prospects”, *Journal of Soil Salinity & Water Quality* 1: 73-84

Guo, Y. 2004. “Economic Evaluation of Genetically Modified R&D Investment. The Case Study of Genetically Modified Rice.” Unpublished paper, Xinjiang Agriculture University, Xinjiang, China.

Heisey, P.W. and Morris, M.L. 2006. “Economic Impact of Water-Limited Conditions on Cereal Grain Production.” *Drought Adaptation in Cereals* 1: 7-48.

Huang, J., Hu, R., and Rozelle, S. 2003. “The Roles of Agricultural Research.” In *Agricultural Research Investment in China: Challenges and Prospects*, Center of Chinese Agricultural Policy Chinese Academy of Sciences, Beijing, China, pp:181.

Huang, J., Hu, R., Meijl, H., and Tongeren, F. 2004. “Biotechnology boosts to crop productivity in China: trade and welfare implications.” *Journal of Development Economics* 75: 27-54.

Li, K. 1999. “Drought disaster research and prevention in China.” *Henan Science /& Technology Press (In Chinese)*

MWR 2000. “China’s Irrigation Development Plan for the 10th Period.” *MWR’s Internal Report*, Beijing, China

MWR 2002. “China Water Resources Bulletin.” *MWR’s Internal Report,* Beijing,China

MWR 2004. “Water resources in China: special issues” *MWR’s Internal Report*, Bejing, China. Available from www.mwr.gov.cn.

MU P., LI, Z., LI, C., ZHANG, H., WU, C., LI, C. and WANG, X. 2003. “QTL Mapping of the Root Traits and Their Correlation Analysis with Drought Resistance Using DH Lines from Paddy and Upland Rice Cross.” *Chinese Science Bulletin*, Vol. 48 No. 24 2718_2724

Nankivell, N. 2004. “China’s Mounting Water Crisis and the Implications for the Chinese Communist Party.” Paper presented at the twelfth annual CANC APS Conference, Quebec Ci ty, 3–5 December 2004. Available from http://www. cancaps.ca/conf2004/nankivell.pdf

O’Toole, J.C. 2004. “Rice and Water: The Final Frontier.” Paper presented on the occasion of H.R.H. Princess Maha Chakri Sirindhorn’s presentation of the Golden Sickle Award to Dr.John C.O’Toole for his contributions to the advancement of rice research over the past 30 years. September 1, 2004, Bangkok, Thailand.

Pandey, S. and Bhandari, H. 2007. “Drought: An Overview.” *In Economic Costs of Drought and Rice Farmers’ Coping Mechanisms: A Cross*-*county Comparative Analysis*. International Rice Research Institute, Los Banos, Philippines, pp: 11-30.

Peng, B. 2008. “Assessment of Research on Water-saving Agricultural Technology in

China- the Case Study of Drought Tolerant." Unpublished paper, Rutgers University, New Brunswick, New Jersey.

Wang, J., Huang J., and Rozelle S. 2005. "Evolution of Tubewell Ownership and Production in the North China Plain." *The Australian Journal of Agricultural and Resource Economics* 49: 177-195

World Bank, 1997. China 2020 Series, "At China's Table: Food Security Options." The World Bank, Washington, K.C. 44p

Zhu, D. 2000. "Bridging the rice yield gap in China." In: Papademetriou MK, Dent FJ, Herath EM, editors. Bridging the rice yield gap in the Asia-Pacific region. Food and Agriculture Organization of United Nations (FAO). Bangkok (Thailand): Regional
Office for Asia and the Pacific

APPENDIX

Table A. Descriptive statistics (Whole sample 160HH)

	Unit	Obs.	Mean	Std. dev.	Min	Max
Variables						
1. Age of HH	year	440	49.54	10.74	25.00	75.00
2. Education of HH	year	440	7.69	2.62	0.00	15.00
3.Farm Size	Mu	440	10.77	10.60	0.75	90.00
4.Growing days	day	403	120.52	9.03	100.00	150.00
5.Herbicide sprayings	No. of time	403	1.22	0.47	0.00	3.00
6. Pesticide sprayings	No. of time	403	3.77	1.14	2.00	7.00
7. Irrigation times	No. of time	403	2.74	2.28	0.00	15.00
8. Cost of Irrigation	yuan/mu	403	10.86	22.42	0.00	200.00
9. Labor	hour/mu	403	30.89	21.80	7.44	257.00
10. Seed use	kg/mu	403	1.33	0.49	0.33	3.00
11. Nitrogen	kg/mu	403	10.80	5.10	2.25	30.50
12. Phosphorus	kg/mu	403	4.20	2.71	0.00	15.00
13. Potassium	kg/mu	403	5.87	3.77	0.00	21.67
14. Fertilizer use	kg/mu	403	54.74	27.42	10.00	166.67
15. Pesticide use	g/mu	403	935.29	393.60	60.00	2000.00
16. Cost of herbicide	yuan/mu	403	4.95	3.58	0.00	20.00
17. Distance	M	403	1008.36	734.01	20.00	5000.00
18. DT rice dummy	1 = yes	403	0.40	0.49	0.00	1.00
19. Transplant	1= seedling transplanting	403	0.28	0.45	0.00	1.00
20. Plot feature	1= susceptible to drought or flood	403	0.34	0.48	0.00	2.00
21. Yield	Kg/mu	403	393.70	65.12	228.57	650.00

Source: Author

Table B. Correlation of variables (Whole sample 160HH)

hage	**heduca**	**growth**	**Tsweed**	**pestnum**	**irrinum**	**cirri**	**qlabor**	**qseed**	**qfert**	**qpest**	**cweeding**	**distnce**	**variety**	**tranmode**	**dfeature**
Age of HH	Education of HH	Growing days	Herbicide sprayings	Pesticide sprayings	Irrigation times	Cost of Irrigation	Labor	Seed use	Fertilizer use	Pesticide use	Cost of herbicide	Distance	DT rice dummy	Transplant	Plot feature

	hage	heduca	growth	tsweed	pestnum	Irrinum	cirri	qlabor	qseed	qfert	qpest	cweeding	distnce	variety	tranmode	dfeature	yield
hage	1.00																
heduca	-0.54	1.00															
growth	0.12	-0.11	1.00														
tsweed	-0.01	-0.02	-0.06	1.00													
pestnum	0.11	-0.13	0.26	-0.08	1.00												
irrinum	-0.19	0.14	-0.29	0.17	-0.07	1.00											
cirri	-0.19	0.24	-0.18	0.12	-0.11	0.38	1.00										
qlabor	0.14	-0.04	0.14	0.02	0.31	-0.01	0.04	1.00									
qseed	-0.12	0.24	-0.23	0.13	-0.31	0.27	0.23	-0.13	1.00								
qfert	-0.04	0.23	0.11	-0.23	-0.03	0.04	0.21	0.03	0.20	1.00							
qpest	-0.04	0.02	0.08	0.15	0.14	0.08	0.08	0.03	0.18	0.05	1.00						
cweeding	0.05	-0.04	0.00	0.28	-0.13	0.01	0.04	0.00	0.21	-0.09	0.30	1.00					
distnce	-0.11	0.19	-0.05	-0.04	-0.14	0.04	0.06	-0.08	0.25	0.35	0.03	-0.06	1.00				
variety	0.01	-0.03	-0.14	0.02	0.01	-0.22	-0.13	-0.01	-0.14	-0.12	0.01	0.02	-0.03	1.00			
tranmode	0.23	-0.22	0.33	-0.20	0.34	-0.34	-0.27	0.35	-0.54	-0.17	-0.08	-0.21	-0.15	0.04	1.00		
dfeature	0.05	-0.06	0.14	-0.14	0.06	-0.07	-0.06	-0.03	-0.03	0.18	-0.02	-0.16	0.12	-0.03	-0.09	1.00	
yield	0.10	-0.18	0.32	-0.05	0.17	-0.16	-0.16	0.11	-0.17	-0.10	0.05	0.01	0.00	0.19	0.22	0.20	1.00

Source: Author

Table C. Spreadsheet to evaluate DT research of Guangxi (Higher Adpt. Scenario) (Yuan)

year	adoprate	deprrate	Se	de	p1	p0	Quan.	K	Z	CS	PS	TS
2008	0.0105	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.001522	0.000938	23,900,000	14,900,000	38,800,000
2009	0.0210	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.003044	0.001876	47,800,000	29,800,000	77,600,000
2010	0.0315	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.004565	0.002814	71,700,000	44,600,000	116,300,000
2011	0.0420	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.006087	0.003752	95,700,000	59,500,000	155,200,000
2012	0.0525	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.007609	0.00469	120,000,000	74,400,000	194,400,000
2013	0.0630	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.00913	0.005628	144,000,000	89,300,000	233,300,000
2014	0.0735	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.010652	0.006566	167,000,000	104,000,000	271,000,000
2015	0.0840	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.012174	0.007505	191,000,000	119,000,000	310,000,000
2016	0.0945	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.013696	0.008443	215,000,000	134,000,000	349,000,000
2017	0.1050	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.015217	0.009381	239,000,000	149,000,000	388,000,000
2018	0.1050	0.05	0.45	0.28	2.5	2.3	11,080,000,000	0.014457	0.008912	227,000,000	141,000,000	368,000,000
2019	0.1050	0.10	0.45	0.28	2.5	2.3	11,080,000,000	0.013696	0.008443	215,000,000	134,000,000	349,000,000
2020	0.1050	0.15	0.45	0.28	2.5	2.3	11,080,000,000	0.012935	0.007974	203,000,000	127,000,000	330,000,000
2021	0.1050	0.20	0.45	0.28	2.5	2.3	11,080,000,000	0.012174	0.007505	191,000,000	119,000,000	310,000,000
2022	0.1050	0.25	0.45	0.28	2.5	2.3	11,080,000,000	0.011413	0.007035	179,000,000	112,000,000	291,000,000
2023	0.1050	0.30	0.45	0.28	2.5	2.3	11,080,000,000	0.010652	0.006566	167,000,000	104,000,000	271,000,000
2024	0.1050	0.35	0.45	0.28	2.5	2.3	11,080,000,000	0.009891	0.006097	156,000,000	96,800,000	252,800,000
2025	0.1050	0.40	0.45	0.28	2.5	2.3	11,080,000,000	0.00913	0.005628	144,000,000	89,300,000	233,300,000
2026	0.1050	0.45	0.45	0.28	2.5	2.3	11,080,000,000	0.00837	0.005159	132,000,000	81,900,000	213,900,000
2027	0.1050	0.50	0.45	0.28	2.5	2.3	11,080,000,000	0.007609	0.00469	120,000,000	74,400,000	194,400,000

Source: Author

Table D. Spreadsheet to evaluate DT research of Guangxi (Lower Adpt. Scenario) (Yuan)

year	adoprate	deprrate	Se	de	p1	p0	Quan.	K	Z	CS	PS	TS
2008	0.0054	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.000783	0.000482	12,300,000	7,650,271	19,900,000
2009	0.0108	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.001565	0.000965	24,600,000	15,300,000	39,900,000
2010	0.0162	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.002348	0.001447	36,900,000	23,000,000	59,800,000
2011	0.0216	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.00313	0.00193	49,200,000	30,600,000	79,800,000
2012	0.027	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.003913	0.002412	61,500,000	38,300,000	99,800,000
2013	0.0324	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.004696	0.002895	73,800,000	45,900,000	120,000,000
2014	0.0378	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.005478	0.003377	86,100,000	53,600,000	140,000,000
2015	0.0432	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.006261	0.003859	98,400,000	61,200,000	160,000,000
2016	0.0486	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.007044	0.004342	111,000,000	68,900,000	180,000,000
2017	0.0540	0.00	0.45	0.28	2.5	2.3	11,080,000,000	0.007826	0.004824	123,000,000	76,500,000	200,000,000
2018	0.0540	0.05	0.45	0.28	2.5	2.3	11,080,000,000	0.007435	0.004583	117,000,000	72,700,000	190,000,000
2019	0.0540	0.10	0.45	0.28	2.5	2.3	11,080,000,000	0.007044	0.004342	111,000,000	68,900,000	180,000,000
2020	0.0540	0.15	0.45	0.28	2.5	2.3	11,080,000,000	0.006652	0.004101	105,000,000	65,100,000	170,000,000
2021	0.0540	0.20	0.45	0.28	2.5	2.3	11,080,000,000	0.006261	0.003859	98,400,000	61,200,000	160,000,000
2022	0.0540	0.25	0.45	0.28	2.5	2.3	11,080,000,000	0.00587	0.003618	92,300,000	57,400,000	150,000,000
2023	0.0540	0.30	0.45	0.28	2.5	2.3	11,080,000,000	0.005478	0.003377	86,100,000	53,600,000	140,000,000
2024	0.0540	0.35	0.45	0.28	2.5	2.3	11,080,000,000	0.005087	0.003136	79,900,000	49,700,000	130,000,000
2025	0.0540	0.40	0.45	0.28	2.5	2.3	11,080,000,000	0.004696	0.002895	73,800,000	45,900,000	120,000,000
2026	0.0540	0.45	0.45	0.28	2.5	2.3	11,080,000,000	0.004304	0.002653	67,600,000	42,100,000	110,000,000
2027	0.0540	0.50	0.45	0.28	2.5	2.3	11,080,000,000	0.003913	0.002412	61,500,000	38,300,000	99,800,000

Source: Author

Table E. Spreadsheet to evaluate DT research of Zhejiang (Higher Adpt. Scenario) (Yuan)

year	adoprate	deprrate	Se	de	p1	p0	quan	K	Z	CS	PS	TS
2008	0.0102	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.001478	0.000911	13,800,000	8,613,439	22,500,000
2009	0.0204	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.002957	0.001823	27,700,000	17,200,000	44,900,000
2010	0.0306	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.004435	0.002734	41,500,000	25,800,000	67,400,000
2011	0.0408	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.005913	0.003645	55,400,000	34,500,000	89,900,000
2012	0.0510	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.007391	0.004556	69,300,000	43,100,000	112,000,000
2013	0.0612	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.00887	0.005468	83,100,000	51,700,000	135,000,000
2014	0.0714	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.010348	0.006379	97,000,000	60,300,000	157,000,000
2015	0.0816	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.011826	0.00729	111,000,000	69,000,000	180,000,000
2016	0.0918	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.013304	0.008201	125,000,000	77,600,000	202,000,000
2017	0.1020	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.014783	0.009113	139,000,000	86,200,000	225,000,000
2018	0.1020	0.05	0.45	0.28	2.5	2.3	6,604,000,000	0.014044	0.008657	132,000,000	81,900,000	214,000,000
2019	0.1020	0.10	0.45	0.28	2.5	2.3	6,604,000,000	0.013304	0.008201	125,000,000	77,600,000	202,000,000
2020	0.1020	0.15	0.45	0.28	2.5	2.3	6,604,000,000	0.012565	0.007746	118,000,000	73,300,000	191,000,000
2021	0.1020	0.20	0.45	0.28	2.5	2.3	6,604,000,000	0.011826	0.00729	111,000,000	69,000,000	180,000,000
2022	0.1020	0.25	0.45	0.28	2.5	2.3	6,604,000,000	0.011087	0.006834	104,000,000	64,700,000	169,000,000
2023	0.1020	0.30	0.45	0.28	2.5	2.3	6,604,000,000	0.010348	0.006379	97,000,000	60,300,000	157,000,000
2024	0.1020	0.35	0.45	0.28	2.5	2.3	6,604,000,000	0.009609	0.005923	90,000,000	56,000,000	146,000,000
2025	0.1020	0.40	0.45	0.28	2.5	2.3	6,604,000,000	0.00887	0.005468	83,100,000	51,700,000	135,000,000
2026	0.1020	0.45	0.45	0.28	2.5	2.3	6,604,000,000	0.00813	0.005012	76,200,000	47,400,000	124,000,000
2027	0.1020	0.50	0.45	0.28	2.5	2.3	6,604,000,000	0.007391	0.004556	69,300,000	43,100,000	112,000,000

Source: Author

Table F. Spreadsheet to evaluate DT research of Zhejiang (Lower Adpt. Scenario) (Yuan)

year	adoprate	deprrate	Se	de	p1	p0	quan	K	Z	CS	PS	TS
2008	0.0024	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.000348	0.000214	3,256,865	2,026,494	5,283,359
2009	0.0048	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.000696	0.000429	6,513,926	4,053,110	10,600,000
2010	0.0072	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.001044	0.000643	9,771,181	6,079,847	15,900,000
2011	0.0096	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.001391	0.000858	13,000,000	8,106,706	21,100,000
2012	0.012	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.001739	0.001072	16,300,000	10,100,000	26,400,000
2013	0.0144	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.002087	0.001287	19,500,000	12,200,000	31,700,000
2014	0.0168	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.002435	0.001501	22,800,000	14,200,000	37,000,000
2015	0.0192	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.002783	0.001715	26,100,000	16,200,000	42,300,000
2016	0.0216	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.00313	0.00193	29,300,000	18,200,000	47,600,000
2017	0.024	0.00	0.45	0.28	2.5	2.3	6,604,000,000	0.003478	0.002144	32,600,000	20,300,000	52,800,000
2018	0.024	0.05	0.45	0.28	2.5	2.3	6,604,000,000	0.003304	0.002037	30,900,000	19,300,000	50,200,000
2019	0.024	0.10	0.45	0.28	2.5	2.3	6,604,000,000	0.00313	0.00193	29,300,000	18,200,000	47,600,000
2020	0.024	0.15	0.45	0.28	2.5	2.3	6,604,000,000	0.002957	0.001823	27,700,000	17,200,000	44,900,000
2021	0.024	0.20	0.45	0.28	2.5	2.3	6,604,000,000	0.002783	0.001715	26,100,000	16,200,000	42,300,000
2022	0.024	0.25	0.45	0.28	2.5	2.3	6,604,000,000	0.002609	0.001608	24,400,000	15,200,000	39,600,000
2023	0.024	0.30	0.45	0.28	2.5	2.3	6,604,000,000	0.002435	0.001501	22,800,000	14,200,000	37,000,000
2024	0.024	0.35	0.45	0.28	2.5	2.3	6,604,000,000	0.002261	0.001394	21,200,000	13,200,000	34,300,000
2025	0.024	0.40	0.45	0.28	2.5	2.3	6,604,000,000	0.002087	0.001287	19,500,000	12,200,000	31,700,000
2026	0.024	0.45	0.45	0.28	2.5	2.3	6,604,000,000	0.001913	0.001179	17,900,000	11,100,000	29,100,000
2027	0.024	0.50	0.45	0.28	2.5	2.3	6,604,000,000	0.001739	0.001072	16,300,000	10,100,000	26,400,000

Source: Author

Table G. 2SLS: SME with instrumental variable: Irrigation cost or Irrigation times on whole sample, 2009

Instrumented Variable	LM (Use Irrigation cost) (1)	Instrumented Variable (Use Irrigation times)	LM (2)
First-stage regression: dependent variable: irrigation			
1. Intercept	48.48 (18.22)	Intercept	8.50 (1.71)
DT rice dummy	-5.21 ** (2.17)	DT rice dummy	-1.16 *** (0.20)
Household age	-0.18 (0.12)	Household age	-0.02 ** (0.01)
Household education	0.84 * (0.49)	Household education	-0.03 (0.05)
Growing days	-0.34 *** (0.13)	Growing days	-0.05 *** (0.01)
fertilizer quantity	0.15 *** (0.04)	fertilizer quantity	-0.007 (0.004)
pesticide quantity	0.003 (0.003)	pesticide quantity	0.0005 ** (0.0003)
Labor	0.13 ** (0.05)	Labor	0.02 *** (0.01)
Transplanting method	-11.6 ** (5.21)	Transplanting method	0.84 * (0.49)
Provincial dummy	-3.31 (6.50)	Provincial dummy	3.45 *** (0.61)
Seed quantity	1.86 (2.86)	Seed quantity	-0.27 (0.27)
Herbicide quantity	-0.065 (0.32)	Herbicide quantity	-0.04 (0.03)
Plot feature	-3.61 (2.29)	Plot feature	-0.14 (0.21)
Distance	-0.002 (0.002)	distance	-0.0004 * (0.0002)
R2	0.18	R2	0.31
Observations	403	Observations	403
Instrumental variables (2sls) regression: dependent variable: yield			
Intercept	418.34 (190.98)	Intercept	337.16 (124.80)
Irrigation cost	-5.65 * (2.97)	Irrigation times	-24.45 ** (12.13)
Variety dummy	-2.19 (21.15)	Variety dummy	1.02 (16.00)
Household age	-1.12 (0.90)	Household age	-0.74 (0.54)
Household education	2.42 (4.11)	Household education	-3.59 * (1.87)
Growing days	0.21 (1.37)	Growing days	0.98 (0.83)
Fertilizer quantity	0.54 (0.46)	Fertilizer quantity	-0.38 ** (0.19)
Pesticide quantity	0.024 (0.019)	Pesticide quantity	0.01 (0.01)
Labor	0.88 * (0.52)	labor	0.65 ** (0.32)
Transplanting method	-58.32 (46.06)	Transplanting method	22.46 (19.26)
Provincial dummy	-17.94 (36.39)	Provincial dummy	66.28 * (38.81)
R2		R2	
Obs.	403	Obs.	403

Source: Author

Table H. 2SLS: SME with instrumental variable: Irrigation cost by location, 2009

Instrumental Variable (Use Irrigation cost)	Guangxi (1)	Instrumental Variable (Use Irrigation cost)	Zhejiang (2)
First-stage regression: dependent variable: irrigation cost			
Intercept	61.60 (27.52)	Intercept	0.53 (5.68)
DT rice dummy	-5.22 * (2.71)	DT rice dummy	-0.40 (0.77)
Household age	-0.33 ** (0.15)	Household age	0.04 (0.05)
Household education	0.70 (0.58)	Household education	0.30 (0.23)
Growing days	-0.45 ** (0.22)	Growing days	-0.04 (0.04)
fertilizer quantity	0.11** (0.06)	fertilizer quantity	0.03 (0.02)
pesticide quantity	0.001 (0.004)	pesticide quantity	-0.0004 (0.0009)
Labor	0.42 *** (0.12)	Labor	-0.001 (0.01)
Transplanting method	-9.83 * (5.93)	Transplanting method	Dropped
Seed quantity	2.39 (3.53)	Seed quantity	0.44 (1.05)
Herbicide quantity	-0.12 (0.41)	Herbicide quantity	-0.08 (0.12)
Plot feature	-3.45 (2.99)	Plot feature	0.73 (0.70)
Distance	-0.001 (0.002)	distance	-0.0002 (0.0009)
R2	0.18	R2	
Observations	312	Observations	91
Instrumental variables (2sls) regression: dependent variable: yield			
Intercept	367.28 (349.86)	Intercept	372.94 (95.98)
Irrigation cost	-6.70 (4.32)	Irrigation cost	11.03 (11.24)
Variety dummy	-4.12 (30.46)	Variety dummy	-5.56 (14.46)
Household age	-1.96 (1.78)	Household age	-0.87 (0.94)
Household education	1.10 (5.30)	Household education	-2.13 (5.00)
Growing days	0.58 (2.60)	Growing days	0.87 (0.83)
Fertilizer quantity	0.42 (0.54)	Fertilizer quantity	-0.004 (0.46)
Pesticide quantity	0.02 (0.03)	Pesticide quantity	-0.008 (0.02)
Labor	3.40 (2.13)	labor	0.07 (0.15)
Transplanting method	-62.51 (56.27)	Transplanting method	Dropped
Instrumented: cirri Instruments: variety hage heduca growth qfert qpest qlabor tranmode qseed cweeding dfeature distance			
Obs.	312	Obs.	

Source: Author

Table I. 2SLS: SME with instrumental variable: Irrigation times by location, 2009

Instrumental Variable (Use Irrigation times)	Guangxi (1)	Instrumental Variable (Use Irrigation times)	Zhejiang (2)
First-stage regression: dependent variable: irrigation times			
Intercept	10.66 (2.52)	Intercept	5.96 (2.28)
DT rice dummy	-1.21 *** (0.25)	DT rice dummy	-0.83 *** (0.31)
Household age	-0.02 (0.01)	Household age	-0.02 (0.02)
Household education	-0.03 (0.05)	Household education	0.05 (0.09)
Growing days	-0.05 (0.02)	Growing days	-0.04 ** (0.01)
fertilizer quantity	-0.002 (0.005)	fertilizer quantity	-0.014 ** (0.008)
pesticide quantity	0.0008 ** (0.0003)	pesticide quantity	0.0003 (0.004)
Labor	0.01 (0.01)	Labor	0.02 *** (0.004)
Transplanting method	0.77 (0.54)	Transplanting method	Dropped
Seed quantity	-0.51 (0.32)	Seed quantity	0.58 (0.42)
Herbicide quantity	-0.01 (0.04)	Herbicide quantity	-0.10 ** (0.05)
Plot feature	-0.30 (0.27)	Plot feature	0.06 (0.28)
Distance	-0.0005 *** (0.0001)	distance	0.0002 (0.0004)
R2	0.15	R2	0.59
Observations		Observations	91
Instrumental variables (2sls) regression: dependent variable: yield			
Intercept	100.18 (130.46)	Intercept	209.95 (144.90)
Irrigation times	-18.69 * (9.88)	Irrigation times	23.40 * (13.51)
Variety dummy	10.86 (14.25)	Variety dummy	13.30 (19.54)
Household age	-0.11 (0.50)	Household age	0.05 (0.81)
Household education	-4.68 ** (1.87)	Household education	-0.33 (3.89)
Growing days	3.03 *** (0.80)	Growing days	1.51 * (0.91)
Fertilizer quantity	-0.27 (0.17)	Fertilizer quantity	0.70 * (0.37)
Pesticide quantity	0.03 ** (0.01)	Pesticide quantity	-0.02 (0.01)
Labor	0.57 (0.38)	labor	-0.51 (0.35)
Transplanting method	9.79 (17.68)	Transplanting method	Dropped
Instrumented: irrinum Instruments: variety hage heduca growth qfert qpest qlabor tranmode qseed cweeding dfeature distance			
Obs.	312	Obs.	91

Source: Author