Land Investment and Tenure Status in South Korea

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Abstract

Despite stringent land ownership and lease regulations, founded on the Land-to-the-Tillers principle prescribed in the Constitution, farmland leasing and non-legitimate rental arrangements are prevalent in South Korea. This study examines the relationship between land tenure status and long-term land investment, specifically the use of organic fertilizer(OF) for paddy-rice farmers. It uses two linked panel data sets from Korea, the Korea Farm Household Economy Survey and the Korea Agricultural Production Cost Survey from 2003 to 2017, each consisting of 3 waves of 5-year-long panels. Eligibility changes for a national organic fertilizer subsidy program allow us to examine the impact of tenure insecurity on OF application. First, we estimate the impact of land ownership on OF application using a log-linear demand function. Then, we use the OF subsidy program eligibility change to identify tenant groups more likely to hold insecure contracts as a proxy for the legality of the rental arrangement. We then compare the OF application between more-secure and less-secure groups. The results show that the OF subsidy eligibility change significantly reduced the intensity of purchased OF among tenant farmers in the second to the fourth quintiles of tenancy ratio. The results also reveal that those farmers in the top quintile paid significantly higher prices for OF while remaining at the same intensity as before. Such results suggest that insecure contracts are prevalent among tenants regardless of their dependency on rented land. However, neither land ownership nor insecure rental arrangements have a considerable impact on OF application, regardless of whether it is purchased or self-supplied. Our empirical evidence explains this counter-intuitive result: (i) the investment cost of OF is relatively small in Korea due to machines and subsidized market products, (ii) the payback period of OF is relatively shorter than other land investments, (iii) Korean rice farmers use OF as complements to inorganic fertilizer rather than substitutes, and (iv) the insecurity embedded in non-legitimate rental arrangements is not severe enough to cause eviction. Therefore, insecure tenure status has limited impacts on OF application of Korean rice farmers.

Key words: Land tenure, Land investment, Organic fertilizer, Input subsidy program, Land-to-the-Tillers principle

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1 Introduction

Secure access to farmland plays an essential role in farm investment decisions, and thus productivity [Feder, 1987, Besley, 1995]. Although well-established land ownership generally protects against land expropriation, farmers in developed economies are not without risks of losing access to land due to their increasing reliance on rental contracts [Adenuga et al., 2021, Bigelow et al., 2016]. In South Korea, the peculiar characteristics of farmland institutions complicate tenure status even more. The country's constitution mandates that farmland must be owned by farmers who cultivate the land through the concept of "Land-to-the-Tillers". In reality, however, about half of farmland is rented and more than 40% of farmland is owned by non-operators as a result of massive rural to urban migration and inheritance to non-operator heirs [Park and Hwang, 2002, Chae et al., 2016, KOSTAT, 2022]. The main consequence of the gap between law and reality is the prevalence of unofficial rental contracts; more than half of rented farmland is presumed to be illegally rented out [Chae et al., 2016]. This situation raises concerns that insecure tenure status could hinder farmers' long-term investment.

Applying organic fertilizer(OF) is one such investment that is specific to land that improves soil quality over several years. Organic fertilizers are made of natural materials such as livestock manure, green manures, and crop residuals. Agronomic research shows that organic fertilizers improve the physical, chemical, and biological properties of soil, which then helps crops to absorb nutrients efficiently and prevent soil acidification and degradation caused by continuous application of inorganic fertilizers [Xu et al., 2008, Ge et al., 2009, Oh et al., 2014, Bhatt et al., 2019]. On the other hand, OF has a much lower nutrient content and is slower in releasing nutrients available to crops than inorganic fertilizer [Bhatt et al., 2019]. It is also known to cost a considerable amount of labor and time to collect, deliver and apply on field due to its weight and the large quantity required [Jacoby and Mansuri, 2008]. Furthermore, the opportunity costs of some OF materials are high; for example, rice farmers could sell rice straw for livestock feed at a good profit [Yoo, 2011, Anonymous, 2000]. Therefore, organic fertilizers are less attractive to tenant farmers who are seeking to maximize short-term profit.

On top of this relationship, the Korean organic fertilizer subsidy program provides an interesting link between tenure status and OF use. The Korean government has subsidized OF since 1999, giving fixed-rate price discounts per unit purchased. The program has exercised substantial power on the market, subsidizing more than 70% of the marketed quantity with a budget of 160 billion KW [Choi and Gouk, 2017]. Any change in this program, therefore, creates ripple effects on OF users and their lands. The most controversial change came in 2016 with respect to subsidy eligibility: the subsidized amount was no longer determined by self-reported area but rather by the officially registered cultivated area. This means those tenant farmers whose landlords avoid official land leasing have to under-report their cultivated area, and therefore are not able to take full advantage of the subsidy. Ironically, the Land-to-the-Tillers principle disincentivizes landlords to join official agreements. Non-operator landlords often register themselves as actual operators so that their landholding is legal with regards to Land-to-the-Tillers; they then rent out the land without authorized contracts. In addition, land inheritance tax exemption, which is given to farmland that is self-operated for at least 8 years to encourage self-operation, further incentivizes such false reporting by non-legitimate landlords. Despite mounting anecdotal evidence of the adverse impact of the eligibility change on tenant farmers, no studies have investigated the impact of the eligibility change on OF use by tenant farmers. Furthermore, to our knowledge, neither the relationship between land tenure and OF use nor the impact of the subsidy program on OF application has been studied in a Korean context.

This study investigates two main research questions focusing on paddy-rice farms which account for more than half of Korean arable land and provide 36% of daily required energy to Korean. The first question asks to what extent land ownership affects OF application. The second question, the main contribution of our paper, examines the impact of the 2016 policy change on OF applications, likely through illegal rental arrangements. In addition, we establish the relationship between the OF subsidy and OF application decision and investigate the impact of OF application on crop revenue to see further welfare implications for OF users.

To answer the questions, we used two linked data sets, the Korea Farm Household Economy

Survey (KFHES) and the Korea Agricultural Production Cost Survey (KAPCS). The KFHES is the most comprehensive annual farm-level survey collecting farm household demographics, income and expenditure, assets, and debt information. The KAPCS randomly selects its sample from the KFHES sample every year and collects data about monetary values and quantities of inputs and outputs at the crop level. We used the survey data from 2003 to 2017, which includes three waves of 5-year-long panels. These comprehensive panel data enable us to control for both observed and time-invariant unobserved factors at a farm level. For the first question, we estimate the log-linear demand function of OF to learn the impact of land ownership. For question 2, we estimate how much OF demand was shifted due to the policy change across tenancy ratio quintiles. Since the legality of contracts is not recorded, we alternatively estimate the policy impact on each tenancy quintile. We identify tenant groups who are likely to hold non-legitimate contracts and thereby have been affected by the policy change. We then compare their OF application with other non-affected groups.

We find that the subsidy program positively affects the intensive and extensive margins of purchased OF; however, its impact on aggregate OF use is not significant. We do not find evidence of the adverse impact of land ownership on OF applications, either purchased or in aggregate. We then find that the eligibility change negatively affected the intensity of purchased OF among the mid-range tenancy quintiles, while the top quintile maintained the intensity at their own expense. However, even these affected groups did not experience significant drops in aggregate OF application. Lastly, we find that the higher proportion of OF investment in total fertilizer expenditure increases crop revenue, which suggests that the policy change decreases crop revenue by 0.05-0.07% by reducing the relative investment of OF.

Our findings contribute to the literature on land tenure impacts on long-term investment and on Korean farmland and organic fertilizer policies. First, it is the first evidence to show that insecure rental arrangements do not disincentivize OF application in the context of developed economies. It could be because farm machines have made OF fertilizer more accessible to farmers by reducing labor costs associated with OF application. Second, our analysis focuses on one crop, paddy rice,

thereby reducing concerns about the endogenous relationship between crop choice, OF application, and tenancy. While previous papers attempted to remove this concern by including a crop dummy variable, we did it by restricting our sample to South Korea's staple crop, paddy rice. It strengthens not only internal validity but also the external validity of these results for rice production. Third, it is the first study that investigates the impact of the Korea OF subsidy program on farmers' fertilizer use. Lastly but most importantly, our quantitative evidence corroborates the anecdotal evidence about the adverse impact of the 2016 policy change on OF application by tenant farmers, which could ultimately damage farmers' welfare as well as soil quality.

This paper is organized as follows. Section 2 explains the Korean land tenure system and the subsidy program, and then present the conceptual framework with a literature review on the mechanism of how land tenure status affects OF application. Section 3 describes the KFHES and KAPCS data sets and our study sample. Section 4 details the empirical econometric models. In Section 5, we present the empirical results. Finally, we discuss and conclude the paper in Section 6.

2 Background

2.1 Land tenure system in Korea

Farmland leasing is prohibited in principle in South Korea by the Land-to-the-Tillers doctrine, first introduced by the Land Reform Act in 1949 and later prescribed in the Constitution (Art.121) in 1987. The principle dictates that farmland must be owned by its operator; if not, the land must be sold to other farmers. This principle aims to protect farmers from landlords who used to exploit tenant farmers before the reform: for example, by taking up to 70 percent of the total harvested crop [Mitchell, 1948]. The land reform was effective: the share of leased land fell sharply from 66% to 8% and the proportion of tenant farm households went from 86% to 8% [KREI, 2019]. Today, both incentives and regulations are used on farmland to implement this principle. The most well-known incentive is the inheritance tax exemption given to land that is self-operated farmland for at least 8 years. Regulations include requirements that heirs of farmland who do not intend to farm, or farmers who exit the industry, must sell off their land in excess of one hectare within a

certain period.

Despite the regulatory efforts, about 50% of farmland is cultivated by tenant farmers, and 42% of farmland is owned by non-operators today through both legitimate and non-legitimate methods [Chae et al., 2016]. Legitimate rental arrangements are provided for through the exceptions listed in the 1996 Farmland Act; these allow certain lands to be rented out for the sake of farm productivity. For example, farmland acquired before the 1996 Farmland Act and farmland owned by retired farmers who operated the land for more than 8 years can be rented out. The legitimately rented area is estimated to account for 42% of total rented land [Chae et al., 2016]. Thus, non-legitimate arrangements take up more than half of the rented land. Although no direct estimates exist, it is suggested that a large portion of non-legitimate rented lands belongs to absentee landlords since non-operators own 86% of the total rented land, and absentee landlords are twice as likely to have non-legitimate contracts than resident landlords [Kim et al., 2008, Chae et al., 2016].

The fixed-rate cash lease is the most popular type of rental arrangement. The farmland leasing survey, which collects data on lease rates and types from the KFHES sample, shows that around 76% of rental arrangements are fixed-rate leases, 7% share leases, and 17% free leases [KOSTAT, 2021]. Among 74% of the fixed-rate leases, the cash lease accounts for 54% and the crop lease for 22%. Rent takes up 15% of total crop revenue on average but differs by cultivation type: 28% for a single-cropping rice paddy, 15% for a double-cropping rice paddy, and 9% for field crops.

2.2 The organic fertilizer subsidy program

The subsidy program was started in 1999 to tackle environmental problems faced by both livestock and agricultural sectors: in particular, the ever-increasing amount of livestock waste, as well as soil erosion and acidification caused by inorganic fertilizer. The subsidy program provides farmers with an organic fertilizer at discounted prices. In this program, the central government sets the total quantity of organic fertilizer and subsidy rates (KW/20kg) every year. Local governments determine the specific quantity for an individual based on one's cultivated area and crop type. Then, farmers purchase the specific quantity of organic fertilizer in-kind at a discounted rate (the

market price net of the subsidy rate) from their chosen suppliers registered in the subsidy program. Local governments and the farmers' cooperative, Nong-hyup, distribute the fertilizer to applicants. While the subsidy rates are first determined by the central government, local governments can then offer additional subsidies from their budgets.

The subsidy program has increased its budget and subsidy rates over the decades (see Figure 5). The budget has increased from 21 to 160 billion KW between 2003 to 2017, which is equivalent to a quantity increase of 0.6 to 3.2 million tons. Although it varies by fertilizer type, the subsidy rate, in general, has risen from 750 to 1600 KW per a 20kg package during the same period. In 2015, one year before the eligibility reform, the subsidy program subsidized about 20% of the market sales, and the subsidized quantity accounted for 70-80% of the total traded quantity on the market [Choi and Gouk, 2017].

In terms of land tenure, the program eligibility underwent a significant change in 2016. Until 2014, any farmer or farm corporation was eligible for the subsidy. In 2015, the eligibility changed to "farm business entities registered to Korean Farm Business Entities Management System", which was introduced to manage individual farm information more effectively in 2008. In the subsequent year, 2016, the eligibility changed to "farmland registered to the management system under the applicant's name". Therefore, tenant farmers could not apply for the subsidy for their rented land if their landlord did not agree to register the rented land under the tenant's name. For example, tenant farmer A operates 10 ha in total, including rented land of 3 ha from landlord B and 2 ha from landlord C. If landlord C refuses to register the rented land under tenant A's name to maintain his access to the inheritance tax exemption, tenant A would end up registering 8 ha to the management system under his name. Thus, a tenant would receive a subsidy for 8 hectares, as the registered area would be used to determine his subsidy amount, while still operating 10 hectares. Therefore, the policy change in 2016 unexpectedly damaged tenant farmers who do not have secure rental arrangements by reducing their access to these subsidized and land-improving inputs.

2.3 Conceptual Framework

Our theoretical framework is founded on Feder [1987] and Besley [1995] that long-term tenure security induces more investments on land and thus more profits; these are called investment enhancing effects. They argue that secure property rights reduce the probability of land expropriation, which increases the likelihood of enjoying future returns from today's investment. While evidence from societies with weak property rights supports this argument, the relationship between ownership and long-term investment is less obvious in societies with a well-developed tenure system [Deininger and Jin, 2006, Bandiera, 2007]. Studies point out that tenant farmers would not treat rented land differently than owned land when they hold a secure long-term contract [Myyrä et al., 2007, Yoder et al., 2008, Leonhardt et al., 2019]. For example, Austrian farmers put equal efforts into soil conservation on both owned and rented lands as they perceived renting as a long-term and secure [Leonhardt et al., 2019]. This is also consistent with Feder's and Besley's theories because a secure long-term contract reduces the risk of land expropriation, leaving farmers indifferent between rented and owned land. Nonetheless, whether Korean tenants follow this pattern, treating the rented land as their own, is an empirical question because of the less-than-legal land rental situation.

A handful of studies investigate this relationship focusing on OF application, as OF is one of the long-term and site-specific investments that affect productivity over more than one agricultural season [Jacoby and Mansuri, 2008, Xu et al., 2008]. These studies, mostly from China and Pakistan, reported the positive impact of secure tenancy on OF applications. Jacoby and Mansuri [2008] found that Pakistani farmers apply less OF on their rented land than on their owned land, but the negative impact of renting is attenuated with a longer rental contract duration. Gao et al. [2017] compared the OF application between private plots and collectively controlled plots, showing higher investment in private plots in China. Xu et al. [2014] and Li et al. [2012] show that a longer lease term enhances OF investment in rented land. Akram et al. [2019] showed that owner-operators invest more OF than sharecroppers and fixed renters in Pakistan. Such findings are consistent with investment-enhancing effects.

This study examines the relationship between land ownership and OF application in the Korean context. The direction of the tenancy impact is subject to investigation because (i) the Korean tenure system greatly differs from other contexts previously studied in the literature, and (ii) the associated cost and benefits of OF application could differ due to different stages of technological and market development. For example, farm machines such as a fertilizer spreader and a straw chopper save a significant amount of labor demanded for OF application. The subsidy program have made organic fertilizer more affordable to farmers. The following hypothesis tests the described relationship.

Hypothesis 1. *The lack of land ownership, measured by the proportion of rented land, may or may not affect farmer's application of organic fertilizer (see equation (1))*

The impact of insecure tenure status on OF application is likely to be exacerbated by the 2016 policy change through the subsidy effects. This relationship can be broken into two components: first, the impact of the subsidy on OF demand; and second, the impact of having an insecure contract on the eligibility for the subsidy. The latter relationship is unique to South Korea and has not yet been investigated; this study is the first research that addresses the linkage between insecure tenure status and OF application, mediated by the exogenous policy shock. The following hypothesis test the described relationships.

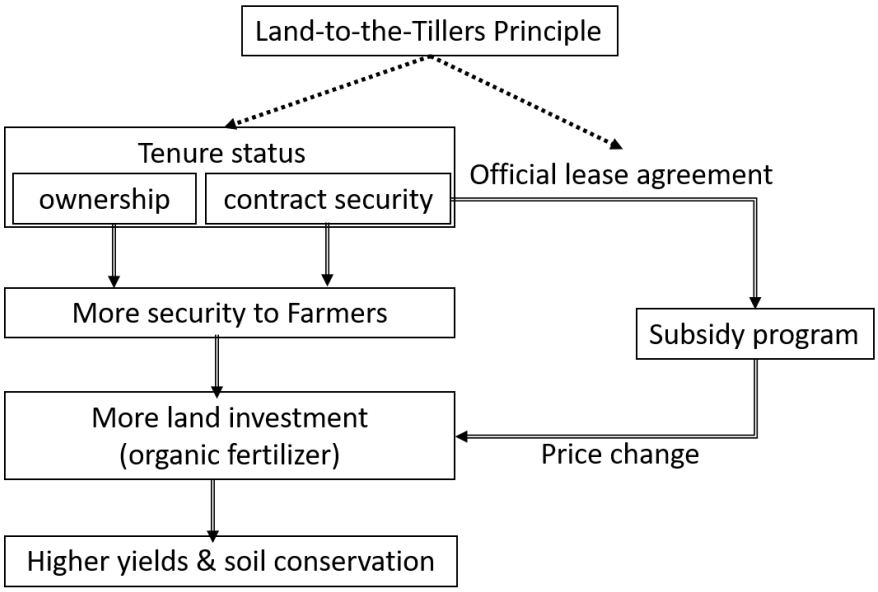
Hypothesis 2. *The subsidy program change has a negative effect on tenant farmers who are likely to hold insecure rental contracts (see equation (2)).*

On the other hand, plentiful research has examined the impact of fertilizer subsidies on demand; however, no studies have attempted to investigate the effects of the Korean organic fertilizer subsidy program. Empirical evidence shows positive direct impacts of fertilizer subsidies on its demand [Kwon, 2005, Wang et al., 2018, Yi et al., 2021]. We test if the Korean OF subsidy program affect OF demand in appendix A.

The last piece of our conceptual framework is the relationship between OF application and farmer's profit. Few papers in agricultural economics have been able to quantify the relationship

between on-farm application of OF and farm profit. Salam et al. [2021] estimated the economic impact of OF on rice farm yield and technical efficiency in Bangladesh using a stochastic production frontier approach and a matching technique. Their estimates suggest that OF users have yields that are 16.7% higher than non-users using less inputs, including labor and capital, and OF users are more efficient by 3.8%. The positive impact is consistent with agronomic findings [Ayoola and Makinde, 2007, Xu et al., 2008, Siavoshi et al., 2011, Lee et al., 2021]. The common finding of these studies is that application of organic manure combined with inorganic fertilizer achieves higher crop yield than using only one kind of fertilizer, as organic matter facilitates crops' nutrient take-up. The yield gap between inorganic-only treatment and the combined fertilizer treatment increases over time, corresponding to the characteristics of long-term investment [Xu et al., 2008]. We test if OF application affects crop revenue in appendix E.

Figure 1: Conceptual Framework



3 Data

3.1 Sampling

This study combines two linked data sets that cover the years 2003 to 2017. The first data set is the Korea Farm Household Economy Survey (KFHES), the most comprehensive annual farm level survey in South Korea; it is composed of 3 waves of 5-year-long panels.[1] The survey offers rich information about farm household demographics, income, expenditure, assets, and debt. For waves 8 and 9, the sample is derived through a stratified two stage cluster sampling method and a systematic stratified sampling method for wave 10, stratified by crop and region. Over time, the sample size has decreased slightly as the farm population decreased: 3,200 farms in wave 8, 2,800 in wave 9, and 2,600 in wave 10. The survey uses self-reported questionnaires and in-person interviews to collect information. Once selected, farm households are required to record their income and expenditure on a monthly basis and to report assets and debt annually. Local interviewers visit their respondents at least twice a month to help with the process. The sample attrition rate is about 5 - 6% every year due to death, illness, or migration. These missing observations are replaced by farm households with similar characteristics.

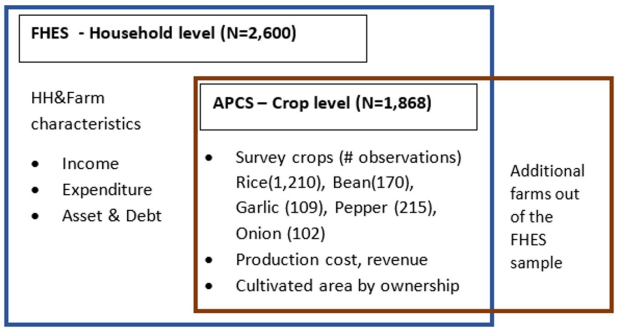
The second data set is the Korea Agricultural Production Cost Survey (KAPCS), the annual crop level survey for commonly grown crops. These crops include rice, barley, pepper, garlic, onion, sesame, and soybean: rice crop accounts for about 60% of the sample. This survey provides detailed information about the monetary values and quantities of inputs used to produce a particular crop, including the total cultivated area, rented area, costs and quantities of chemical, self-made organic, and purchased organic fertilizers at the crop level. The KAPCS randomly selects farms from the KFHES sample every year that meet minimum cultivated area requirements: for rice, farmers who cultivate more than 1,980m^2 (see figure 2). Since it uses the KFHES sample pool, most of the crop-farm units are recorded for several years. In 2016, about 95% of crop-farm units were recorded for more than two years and about 50% of the sample was observed for all five years

[1]The KFHES started from 1953 and has carried out until now. The 5-year-long panel data sets have 10 waves completed until 2017. However, only the last three waves (2003-2017) are accessible through Microdata Integrated Service of Statistics Korea.

of the survey wave.

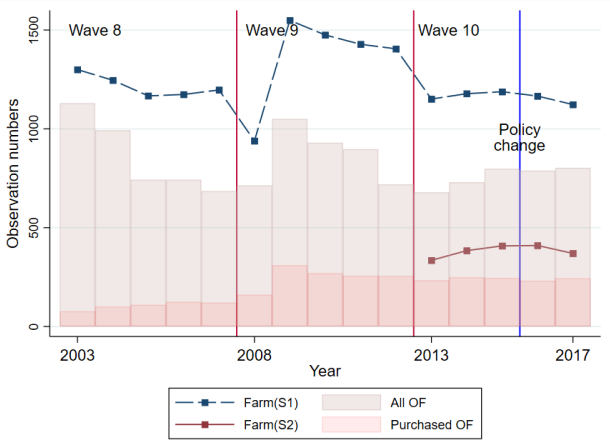
Figure 3 displays the number of rice farms and the number of OF users over the observed years. This study use two samples to examine different effects of interest. Sample 1 is used to estimate the subsidy impact and the ownership impact throughout 2003 to 2017. This sample contains a total of 18,686 farm-year observations from the three waves: the average number of farms is 1,803, 1,917, and 1,653 for waves 8, 9, and 10, respectively. Sample 2 is used to estimate the 2016 policy change impact. This sample includes farmers who have purchased OF at least once before the policy change in wave 10 (2013 - 2017). It leaves a total of 1,907 observations from 411 farms.

Figure 2: Data Structure



Note: The APCS surveys additional 40 farms that cultivate rice or onion aside from the FHES sample to ensure enough sample size.

Figure 3: The number of observations



Note: Sample 1 (S1) contains a total of 5,373 farms from the three waves. Sample 2 (S2) includes 411 farms from wave 10, reported to have applied purchased OF before the policy change.

3.2 Summary Statistics

Table 1 describes farm household characteristics and farm inputs and outputs from sample 1. An average farm operates 1.82 ha of farmland in total, including 1.15 ha for rice. Rice farming is mechanized; the average ratio of machine running hours to human labor hours is 0.37 and the value of machinery and equipment both owned and rented is 19.4 million KW on average in real value (2015=100).[2] About 23% of production costs are spent on custom service such as tillage, transplanting, harvesting and drying rice. The current ratio measures a farm's ability to pay short

[2]This machinery asset worth is approximately 68% of Korean GDP per capita during this period (2003-2017): the average GDP per capita is 28.4 million KW (25,803 US dollars) in real value.

term obligations. More than half of farms do not have current liabilities; we censor their current ratios at 200 to prevent infinite numbers. The average current ratio of the sample is about 131.[3] In terms of revenue and cost, farmers earn 892 KW/m^2 on average and spend 30% of their revenue on land rent if rent is paid, 21% on labor, 6% on equipment, and 5% on fertilizer. OF cost accounts for 21% of total fertilizer expenditure, captured by Fratio1.

Crucially for our interest, farmers rent in about 39% of the cultivated area on average. We use tenancy ratio to measure land ownership, which is the proportion of rented area in the total cultivated area. The overall standard deviation of tenancy ratio across farms is 0.39: the between farm variation is 0.38 and the within farm variation is 0.10 across observed years. Another important variable of tenure status is the legality of farms' rental arrangements, which are not observed. Instead, as a proxy, we break the sample at the different quintiles of tenancy ratio and identify tenant quintiles who are likely to hold illegal contracts.

Table 2 describes sample 2's farm household characteristics broken up by tenancy quintile. The first quintile is self-operators without any rented land. On average, the second quintile rents 12% of their cultivated area, the third quintile 36%, the fourth quintile 64%, and the fifth quintile 96%. Self-operators are older, less educated, and have smaller household sizes. In terms of farming scale, both farm and cultivated area are the largest in Q4 but the smallest for Q1. Q4 and Q5 own and rent more machinery and equipment than other groups. However, the crop revenue per area is similar across all groups, and the financial liquidity ratio is generally high. Most of the farmers in sample 2 applied organic fertilizers, and more than half of OF users have applied purchased OF each year. The average intensity of OF application, both aggregated and purchased, is similar across quintiles. This is in spite of the fact that livestock assets are particularly higher for Q3 and Q4.

[3] A farm is generally considered financially healthy when its current ratio is 2 or above: the farm has more than twice as many current assets as current liabilities. However, a very high current ratio could indicate inefficient use of assets and finance.

Table 1: Summary statistics (Sample 1)

	Mean	SD	Min	Median	Max
Fertilizer Use					
Aggregated organic fertilizer (kg/m2)	0.23	0.28	0.00	0	6
Self-supplied organic fertilizer (kg/m2)	0.20	0.26	0.00	0	4
Purchased organic fertilizer (kg/m2)	0.036	0.13	0.00	0	4
Whether to use OF (=1 if yes)	0.66	0.47	0.00	1	1
Whether to purchase OF (=1 if yes)	0.16	0.37	0.00	0	1
Proportion of aggregated OF in total fertilizer in value (Fratio1) (%)	0.21	0.21	0.00	0	1
Inorganic fertilizer (kg/m2)	0.073	0.068	0.00	0	4
Market and Subsidy variables					
Relative organic fertilizer price to crop price	0.087	0.054	0.00	0	1
Relative inorganic fertilizer price to crop price	0.43	0.33	0.03	0	22
The likely subsidized quantity (kg/m2)	0.13	0.059	0.03	0	0
Household characteristics					
Operator's age	64.5	10.2	29.00	66	92
Operator's sex (=1 if male)	0.95	0.21	0.00	1	1
Household size	2.76	1.21	1.00	2	13
Proportion of medical expense in total consumption (%)	0.094	0.096	0.00	0	1
[EDU]No formal schooling	0.12	0.33	0.00	0	1
[EDU]Elementary school graduated	0.40	0.49	0.00	0	1
[EDU]Middle school graduated	0.21	0.41	0.00	0	1
[EDU]High school graduated	0.24	0.42	0.00	0	1
[EDU]College graduated	0.030	0.17	0.00	0	1
Farm characteristics					
Total farmsize (ha)	1.82	1.84	0.01	1	40
Proportion of off-farm income (%)	0.35	0.33	0.00	0	1
Livestock value (Million KW)	14.5	56.0	0.00	0	1,159
Farm equipment asset (Mil.KW)	19.4	25.4	0.00	10	588
Current ratio (%); capped at 200	131.3	88.6	0.02	200	200
Crop-level characterstics					
Cultivated area (ha)	1.15	1.47	0.16	1	36
Tenancy ratio:proportion of rented land (%)	0.39	0.39	0.00	0	1
Custom work:proportion of custom work cost(%)	0.23	0.14	0.00	0	1
Mechanization:power/labor in hours	0.37	0.68	0.00	0	37
Revenue and Input variables					
Crop revenue (KW/m2)	892.2	161.3	30.36	887	2,072
Land rent (KW/m2)	266.0	76.8	6.41	270	780
Labor cost (KW/m2)	183.8	79.1	8.68	173	945
Pesticide cost (KW/m2)	34.3	18.6	0.00	33	296
Seed cost(KW/m2)	18.3	20.2	0.00	14	204
Fertilizer cost (KW/m2)	45.6	22.5	0.00	43	561
Farm equipment cost (KW/m2)	57.4	66.0	0.00	33	1,554
Observations	18686				

Note: Standard deviations are in parentheses. All monetary values are adjusted to 2015 Korean won.

Table 2: Summary statistics(Sample2)

	Q1	Q2	Q3	Q4	Q5
Tenancy ratio					
Maximum tenancy ratio	0	0.22	0.49	0.80	1
	(0)	(0.054)	(0.057)	(0.073)	(0)
Tenancy ratio:proportion of rented land (%)	0	0.12	0.36	0.64	0.96
	(0)	(0.14)	(0.19)	(0.19)	(0.094)
Organic fertilizer use before the policy change					
Aggregated organic fertilizer (kg/m2)	0.27	0.26	0.26	0.28	0.28
	(0.35)	(0.32)	(0.29)	(0.39)	(0.35)
Self-supplied organic fertilizer (kg/m2)	0.18	0.16	0.17	0.19	0.19
	(0.29)	(0.25)	(0.26)	(0.29)	(0.28)
Purchased organic fertilizer (kg/m2)	0.097	0.098	0.091	0.092	0.091
	(0.20)	(0.23)	(0.16)	(0.23)	(0.21)
Whether to use OF (=1 if yes)	0.75	0.78	0.79	0.80	0.80
	(0.43)	(0.42)	(0.41)	(0.40)	(0.40)
Whether to purchase OF (=1 if yes)	0.42	0.43	0.45	0.43	0.43
	(0.49)	(0.50)	(0.50)	(0.49)	(0.49)
Inorganic fertilizer (kg/m2)	0.070	0.075	0.079	0.078	0.074
	(0.058)	(0.067)	(0.074)	(0.069)	(0.057)
Household characteristics					
Operator's age	68.2	67.0	66.2	63.0	62.4
	(8.77)	(9.25)	(9.06)	(9.40)	(9.55)
Operator's sex(=1 if male)	0.94	0.94	0.96	0.98	0.97
	(0.23)	(0.23)	(0.19)	(0.15)	(0.17)
Household size	2.51	2.68	2.59	2.70	2.97
	(1.05)	(1.18)	(1.15)	(1.10)	(1.30)
Medical expense(%)	0.10	0.10	0.10	0.086	0.085
	(0.099)	(0.10)	(0.10)	(0.088)	(0.085)
High school graduated	0.19	0.24	0.29	0.28	0.22
	(0.39)	(0.43)	(0.45)	(0.45)	(0.41)
College graduated	0.032	0.038	0	0.020	0.042
	(0.18)	(0.19)	(0)	(0.14)	(0.20)
Farm characteristics					
Total farmsize (ha)	1.13	1.52	2.16	2.73	2.36
	(0.77)	(1.17)	(1.66)	(2.26)	(2.50)
Off-farm income (%)	0.36	0.34	0.27	0.31	0.42
	(0.33)	(0.33)	(0.29)	(0.31)	(0.34)
Livestock value (Million KW)	5.28	12.4	17.5	21.1	14.2
	(26.8)	(60.0)	(61.7)	(65.2)	(60.3)
Farm equipment asset (Million KW)	14.2	16.2	20.3	30.0	26.8
	(26.5)	(18.0)	(22.5)	(32.0)	(32.6)
Current ratio (%); capped at 200	150.3	148.0	130.5	120.8	117.3
	(80.7)	(81.1)	(89.0)	(90.5)	(92.1)
Crop-level characterstics					
Crop revenue (KW/m2)	915.6	942.1	916.2	915.5	896.7
	(177.3)	(168.6)	(156.1)	(163.0)	(174.6)
Cultivated area (ha)	0.64	0.98	1.44	1.93	1.50
	(0.49)	(0.88)	(1.34)	(2.08)	(1.85)
Land rent (KW/m2)	261.4	257.7	258.1	259.5	252.6
	(65.6)	(83.0)	(73.4)	(69.2)	(74.5)
Observations	1292	632	960	955	952

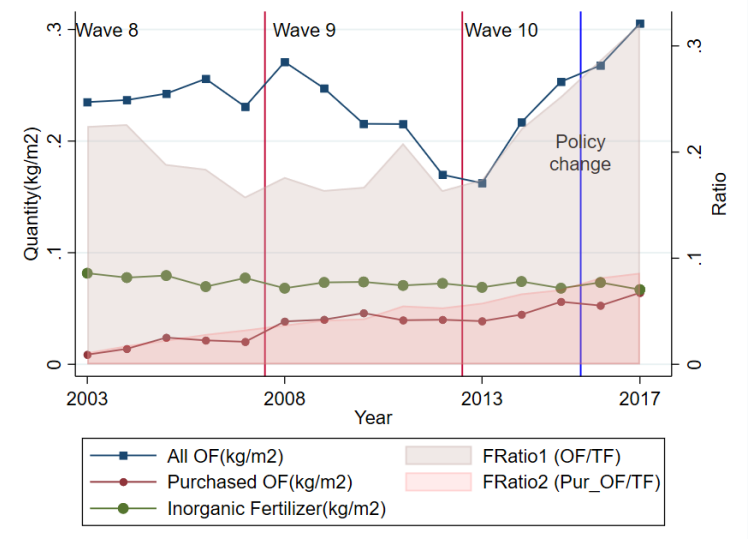
Note: Standard deviations are in parentheses. All monetary values are adjusted to 2015 Korean won.

3.3 Land investment variables

We measure farmers' fertilizer behavior using six dependent variables. The first variable is a binary measure of whether or not the operation used purchased OF. The second variable measures whether or not the operation used any type of OF. Other four variables measure the intensity of self-supplied OF, purchased OF, aggregated OF, and inorganic fertilizer use in kg per a square meter, respectably: aggregated OF is the sum of self-supplied and purchased OF.

Table1 shows that 66% of the farm-year observations used OF and 16% applied purchased OF on their crops. In figure 3, the number of farms that use any OF declines over time in waves 8 and 9, while slightly increasing in wave 10. The proportion of farms that apply purchased OF slightly increases or remains constant. In terms of the intensity of fertilizer use, farmers applied OF of about 0.23 kg/m^2 on average, including purchased OF of about 0.04 kg/m^2. Figure 4 shows the gradual growth of purchased OF and the steady use of inorganic fertilizer.

Figure 4: Organic fertilizer use change



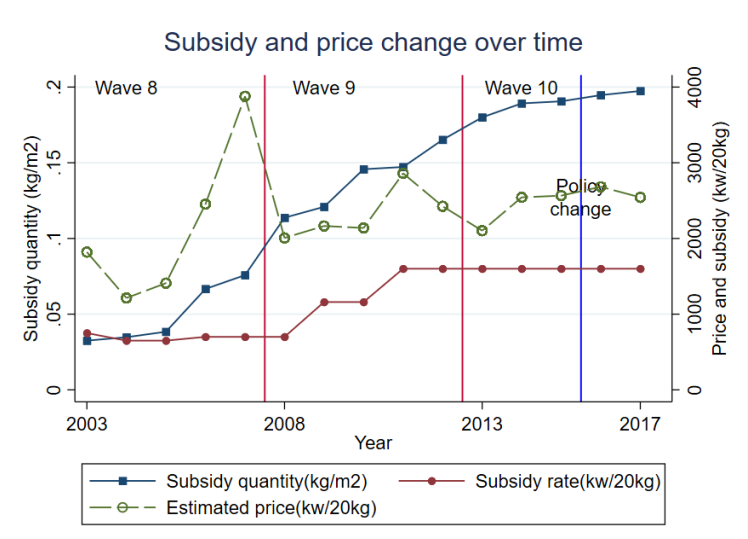
3.4 Subsidy variables and its effect

3.4.1 Subsidy variables

Figure 5 shows the trends in the subsidy amount and in the estimated market prices of OF. Subsidy quantity indicates the likely amount of subsidized OF per area, calculated by dividing the total

national subsidized OF quantity by the national farmland area for each year: how much organic fertilizer would be given to each square meter of farmland if distributed equally. The subsidy quantity rapidly increased during 2003-2013 due to expansion of the subsidy program and reduction in farmland. As a result, the estimated quantity used increased from 0.03 to 0.2 kg/m2 from 2003 to 2017. Subsidy rate is the amount of subsidy given per 20kg of OF. This rate has been rather constant: subsidy rate rose from about 700KW to 1,600KW per 20kg during the ninth wave period and remained constant most of the observed years. The estimated price is computed by dividing the farm's total expenditure on purchased OF by its quantity used; therefore, the estimated prices vary by farm and year[4].

Figure 5: Subsidy and price change



3.4.2 Subsidy effect

We estimate the impact of the subsidy program on OF application along with other determinants: see appendix A for the model specification. Table 3 presents the significantly positive subsidy impacts on OF application. A 1% increase in subsidy quantity raises the intensity of purchased OF application by 1.95 % and the probability of applying purchased OF by 0.3 %, holding other variables constant. On the other hand, the subsidy program does not affect the intensity of inorganic

[4]We does not estimate or control for the impact of subsidy rate aside from the impact of the increasing likelihood of receiving subsidy, captured by subsidy quantity. First, the variance of subsidy rate is very small across time: it has only five unique values during the 15 years. Second, the central government's rate is not likely to capture the subsidy rate that farmers received due to local government's additional subsidy.

fertilizer application.

Table 3: The impact of the subsidy program on fertilizer use

	ln(POF)		WPO[LPM]		ln(IF)	
	(1)	(2)	(3)	(4)	(5)	(6)
Subsidy quantity	1.22***	1.27***	0.20***	0.21***	-0.11***	-0.16***
	(0.065)	(0.092)	(0.013)	(0.019)	(0.021)	(0.029)
Observations	18565	18565	18565	18565	18565	18565
Farm FE	No	Yes	No	Yes	No	Yes

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) Dependent variables are as follows: Purchased OF (POF), Whether to apply purchased OF (WPO), Inorganic fertilizer (IF). (3) Models (1), (3), and (5) control for wave and region fixed effects. Models (2), (4), and (6) control for farm fixed effects. (4) All models control for farm and household characteristics: age, sex, household size, health, education, cultivated area, off-farm income, current ratio, farm equipment asset, livestock value, inorganic and organic fertilizer prices, and tenancy ratio.

4 Empirical method

4.1 Model 1: Impact of land ownership on OF application

The first model estimates the impact of land ownership on OF application. The model restricts its sample to the pre-intervention period (2003-2015) to remove the policy change effect from land ownership effect: the subsidy eligibility change could affect tenant farmers' fertilizer use through non-legitimate tenure contracts. The model specification is as follows:

$$ln(Y_{it}) = \beta_0 + \beta_1 Ownership_{it} + \beta_2 ln(Prices_{it}) + \beta_3 X_{it} + \beta_{rt} + \varepsilon_{it} \quad (1)$$

This model includes three dependent variables Y_{it}: the intensity of aggregated OF and purchased OF application in kg per a square meter, and whether to use purchased OF, for farm i in year t. $Ownership_{it}$ includes two measurements of land ownership: tenancy ratio and tenancy quintile. $Tenancy\ ratio_{it}$ is the proportion of rented farmland out of total operated land for farm i in year t. $Tenancy\ quintile_i$ is a categorical variable of tenancy ratio: farmers in sample 1 is divided into quintiles based on farms' mean tenancy ratios. We use this discrete variable to address the concern of a non-linear relationship between land ownership and dependent variables. Following the

previous literature on determinants of fertilizer use, we control for the market, demographic and farm characteristics that affect farmers' behavior [Abdoulaye and Sanders, 2005, Chibwana et al., 2010, Kousar and Abdulai, 2016, Wang et al., 2018, Daadi and Latacz-Lohmann, 2021]. $Prices_{it}$ include the estimated relative prices of organic fertilizer and inorganic fertilizer for farm i at year t. The relative prices of fertilizer are obtained by dividing the reported purchase price of fertilizer by the reported price received for the crop. Following the law of demand, we expect negative own price effects. The direction of cross-price effects is determined by the relationship between organic and inorganic fertilizer; Kwon and Kang (1999) found that these are substitutes based on a non-parametric specification [Kwon and Kang, 1999].

$\mathbf{X_{it}}$ accounts for various demographic and farm characteristics for farm i in year t. Demographic variables include farmer's age, sex, household size, health, and education. Age approximates a farmer's experience, and their education level reflects, in part, their knowledge or ability to acquire knowledge. Farm household's health condition is proxied by the proportion of medical expenditure in total consumption. Household size is a proxy for available family labor; family members supply 86% of total farm labor in hours per year, on average. Applying OF requires higher labor inputs, hence poor farmer health or a smaller labor pool could negatively affect its use [Daadi and Latacz-Lohmann, 2021]. Farm characteristics include cultivated area, farm equipment assets, off-farm income, liquidity indicator (current ratio), and livestock assets. Cultivated area represents farms' scale of rice operations. Farm equipment assets represents farm's reliance on machines instead of labor. We expect more mechanized farms to apply more OF as those farms are likely to use fertilizer spreaders that save human labor. Off-farm income is the ratio of off-farm income to household regular income.[5] Off-farm income may have ambiguous effects on the intensity of organic fertilizer use; on one hand, it may enhance OF use by relaxing budget constraints, one the other hand, off-farm work may compete time and labor with OF tasks [Kousar and Abdulai, 2016]. In the same context, we also control for the farm's liquidity, which affects farmers' access to credit and cash using the current ratio. Lastly, the manure availability would have a positive impact on OF use, especially for self-supplied organic fertilizer [Abdoulaye and Sanders, 2005]. In this study, we

[5]Household regular income is the earnings from regular sources such as farm income and off-farm income, excluding non-regular sources such as lottery and money gift.

approximate the manure quantity by livestock value owned by each farm household.

Farmer's fertilize use decision can be affected by natural and macro-economic factors. We address this concern by accounting for region-year fixed effects, denoted by β_{rt}.[6]. We also test farm fixed effects to control for unobserved farm characteristics; however, we prefer the region-year fixed model over the farm fixed model because of the small within farm variance of tenancy ratio (see section 3.2).

4.2 Model 2: Impact of 2016 policy change on OF application

The second model estimates the impact of the 2016 policy change on OF use for tenant farmers, and how their tenure status interacts with the policy impact. To do so, we restricts its sample to farmers who have purchased organic fertilizer at least once, before the policy change. We use a farm fixed model to control for time-invariant unobserved farm characteristics such as farmers' managerial skills. The policy effects are separately estimated for different tenant groups: farmers are grouped into quintiles based on their average tenancy ratio.

$$Y_{it} = \delta_0 + \delta_1 Year_t + \delta_2 ln(Prices_{it}) + \delta_i + \varepsilon_{it} \tag{2}$$

Equation (2) shows the specification of the model. The four dependent variables, denoted by Y_{it}, are used to measure the following: whether the operation used purchased OF, the intensity of purchased OF use, the intensity of aggregate (purchased plus self-made) OF, and the log of OF price for farm i in year t. We include OF price, computed from farmers' actual payment on purchased OF, to capture farmers' alternative response to the policy shock: they pay the full cost of OF rather than reducing the intensity of OF application. The coefficients of interest are δ_2 (2016) and δ_2 (2017), as $Year_t$ captures the level change of the outcome variables in each year relative to 2015. $Prices_{it}$ include relative organic and inorganic fertilizer prices. Instead of individually

[6]The inclusion of year fixed effects is the major difference between the subsidy model (equation (1)) and the ownership model (equation (3)). We could not include year fixed effects in the subsidy model because the subsidy variable vary by year.

computed prices, we use the regional average OF prices paid by self-operators to avoid direct subsidy effects on OF prices at a farm level; the OF prices vary by region and year, not by farm. For the analysis for the policy impact on price, we use the absolute value of prices (KW/kg) instead of relative prices for both dependent and control price variables. δ_i indicate a farm household dummy. Farm and household characteristic variables are not included due to their small variance across time.

In this analysis, we assume that no other factors than the policy change affect farmers' OF decision in 2016 and 2017. One endogeneity problem may arise from the sample selection, as we restrict the sample to those who have used purchased OF during the pre-intervention period. If farmers' OF decision is dependent on their past decision, it would cause significant drops in OF application in the post-intervention period without the policy shock. In appendix D, we conduct an additional analysis to see to what extent this sample selection affects the dependent variables.

5 Results

5.1 Impact of land ownership on OF application

Table 4 presents the land ownership impacts on fertilizer use from three different specifications; pooled OLS, farm FE, and POLS with a factor variable of tenancy ratio. The estimates of tenancy ratio show insignificant linear impacts on organic fertilizer use. Column (3) indicates that tenant farmers who rent more the land they operate, the firth and fifth quintiles, do not invest less OF than self-operators.[7] In Columns (4) and (9), no significant differences in purchased OF are observed between tenancy quintiles. The estimates of fertilizer prices again show the negative own price effects of each fertilizer and the complementary relationship between organic and inorganic fertilizer.

[7]More detailed analysis of the ownership impact by quintile is offered in appendix B.

5.2 Impact of the 2016 policy change on OF application

Table 5 presents farm FE estimates of 2016 policy change impacts on farmers' OF investment by quintile. The probability of applying purchased OF by tenant farmers in Q2-Q5 significantly falls by 18-34% in 2016 and 2017 relative to 2015. The intensity of purchased OF application also significantly decreases for tenant farmers in Q2-Q4 in 2016. The quantity of purchased OF applied dropped by about 0.1kg/m^2 for operators in Q2 and Q4 and 0.07kg/m^2 for operators in Q3 following the policy change. However, the coefficients of tenant farmers become similar to that of self-operators in the following year, 2017. For the price dependent variable, the top quintile shows a significant rise in paid price of OF in 2016-17. Lastly, the intensity of aggregated OF use remains unaffected for all the quintiles.

Table 4: The impact of land ownership on OF application

	ln(AOF)			ln(POF)			WPO[LPM]		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Main variables									
Tenancy ratio	-0.12	-0.20		-0.07	-0.07		-0.01	-0.02	
	(0.068)	(0.205)		(0.041)	(0.157)		(0.008)	(0.033)	
Tenancy quintile 2			0.34***			0.01			0.00
			(0.094)			(0.057)			(0.012)
Tenancy quintile 3			0.29***			0.08			0.02
			(0.074)			(0.046)			(0.009)
Tenancy quintile 4			0.12			-0.03			-0.00
			(0.079)			(0.046)			(0.010)
Tenancy quintile 5			-0.04			-0.07			-0.01
			(0.077)			(0.045)			(0.009)
Market variables									
OF price	-1.06***	-0.56***	-1.05***	-2.20***	-1.34***	-2.20***	-0.34***	-0.21***	-0.34***
	(0.050)	(0.056)	(0.050)	(0.087)	(0.065)	(0.087)	(0.018)	(0.013)	(0.018)
IF price	-0.35***	-0.03	-0.33***	-0.15**	0.05	-0.15**	-0.04***	0.00	-0.04***
	(0.058)	(0.070)	(0.057)	(0.052)	(0.056)	(0.052)	(0.010)	(0.012)	(0.010)
Observations	16276	16276	16276	16276	16276	16276	16276	16276	16276
Farm FE	No	Yes	No	No	Yes	No	No	Yes	No

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) Dependent variables are as follows: Aggregated OF (AOF), Purchased OF (POF), Whether to apply purchased OF (WPO). (3) Columns (2), (5), and (8) use a farm fixed model. Other columns use a pooled OLS with region-year fixed effects. (4) All columns control for farm and household characteristics: age, sex, household size, health, education, cultivated area, off-farm income, current ratio, farm equipment asset, livestock value. (5) The mean tenancy ratios of each tenancy quintile are as follows: Q1 (0), Q2 (0.09), Q3 (0.31), Q4 (0.64), and Q5 (0.97). (6) Full estimates are in table A2

.

Table 5: 2016 Policy impact on OF application

	POF					WPO				
	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5
2013	-0.10**	-0.12*	-0.06	-0.06	-0.07	-0.17	-0.24	-0.04	-0.09	-0.04
	(0.034)	(0.047)	(0.037)	(0.037)	(0.037)	(0.095)	(0.131)	(0.125)	(0.106)	(0.122)
2014	-0.02	-0.07	-0.03	-0.02	-0.07	-0.00	-0.13	-0.03	0.02	-0.01
	(0.031)	(0.041)	(0.037)	(0.035)	(0.038)	(0.087)	(0.124)	(0.093)	(0.104)	(0.101)
2015										
2016	-0.02	-0.09*	-0.07**	-0.10**	-0.09	-0.15	-0.34***	-0.18*	-0.29***	-0.25***
	(0.030)	(0.036)	(0.025)	(0.029)	(0.047)	(0.078)	(0.093)	(0.080)	(0.072)	(0.073)
2017	-0.08**	-0.08*	-0.08*	-0.05	-0.07*	-0.24**	-0.41***	-0.34***	-0.22*	-0.29***
	(0.030)	(0.041)	(0.032)	(0.035)	(0.031)	(0.072)	(0.092)	(0.081)	(0.090)	(0.074)
Price variables										
OF price	-0.14**	-0.12	-0.09	0.01	0.03	-0.39**	-0.21	-0.33*	-0.10	-0.20
	(0.046)	(0.070)	(0.055)	(0.038)	(0.079)	(0.136)	(0.173)	(0.164)	(0.142)	(0.152)
IF price	-0.01	-0.00	-0.02	-0.01	-0.04	-0.06	0.10	0.08	-0.06	-0.02
	(0.022)	(0.027)	(0.033)	(0.028)	(0.035)	(0.075)	(0.104)	(0.099)	(0.062)	(0.081)
	AOF					ln(Price)				
	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5
2013	-0.14***	-0.19**	-0.16**	-0.14**	-0.17**	-0.13	0.06	-0.02	-0.30*	-0.15
	(0.040)	(0.056)	(0.059)	(0.052)	(0.053)	(0.074)	(0.136)	(0.133)	(0.142)	(0.116)
2014	-0.05	-0.11*	-0.06	-0.07	-0.06	-0.05	0.11	0.01	-0.14	0.07
	(0.033)	(0.048)	(0.046)	(0.049)	(0.055)	(0.078)	(0.132)	(0.106)	(0.119)	(0.088)
2015										
2016	-0.00	-0.02	-0.04	-0.06	-0.08	-0.06	0.17	0.09	0.12	0.15*
	(0.035)	(0.051)	(0.039)	(0.053)	(0.086)	(0.064)	(0.110)	(0.086)	(0.085)	(0.064)
2017	-0.02	-0.01	0.02	-0.04	0.00	-0.08	0.05	0.17	-0.04	0.15*
	(0.042)	(0.061)	(0.048)	(0.041)	(0.072)	(0.073)	(0.118)	(0.089)	(0.090)	(0.063)
Price variables										
OF price	0.08	0.02	-0.07	0.11	0.11	0.91***	0.72**	0.73***	0.11	0.66***
	(0.061)	(0.079)	(0.073)	(0.067)	(0.181)	(0.116)	(0.216)	(0.214)	(0.175)	(0.170)
IF price	-0.04	-0.02	-0.03	0.00	-0.07	0.11	-0.10	0.05	-0.07	-0.06
	(0.039)	(0.045)	(0.039)	(0.035)	(0.073)	(0.081)	(0.114)	(0.101)	(0.114)	(0.073)
Observations	480	284	384	381	378	480	284	384	381	378

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) The sample contains farmers who have purchased OF at least once, before the policy change, in the wave 10. (3) The dependent variables are as follows: Purchased OF (POF), whether to buy purchased OF(WPO), aggregated OF (AOF), and the estimated OF price (Paid price). (5) All regressions control for farm fixed effects. (6) The mean tenancy ratios of each tenancy quintile are as follows: Q1 (0), Q2 (0.12), Q3 (0.36), Q4 (0.64), and Q5 (0.96).

6 Discussion and Conclusion

The paper analyzes the impact of land tenure status on OF application of rice farmers in South Korea. We estimated the impact of the subsidy program on OF application along with other determinants of fertilizer demand and found that the subsidy had a positive impact on the application of purchased OF. We then estimated the impact of the eligibility change of the subsidy program on farmers' OF decisions for each tenancy quintile using farm fixed effects. The result indicates that the mid-range quintiles significantly reduce the intensity of purchased OF application in response to the policy shock. Although the top quintile does not reduce the intensity of purchased OF at a significant level, they pay a higher price for the product after the policy change. These estimates are plausible as well, except that of the second quintile: given the tenancy ratio, the policy shock likely reduces purchased OF by 0.03kg/m^2 for Q2, 0.08kg/m^2 for Q3, 0.13kg/m^2 for Q4, and 0.21kg/m^2 for Q5.[8] We also tested if the sample selection causes the significant reduction in purchased OF application considering that farmers tend to skip or apply less purchased OF when they did in recent years (see appendix D); the sample selection significantly reduces the probability of purchased OF use, but not the intensity measure. Such results suggest the significant adverse impact of the eligibility change on the intensity of purchased OF across all tenancy quintiles through non-legitimate contracts; tenant farmers either/both reduced the OF investment or/and remained the same at their own expense.

Having found the prevalent non-legitimate rental arrangements across all tenancy quintiles, we tested the impact of land ownership on OF applications during the pre-intervention period. The overall finding suggests no significant impact of land ownership on any type of OF. Lastly, the positive contribution of OF investment to crop revenue is shown. We estimate that the impact of the policy shock decrease crop revenue by 0.05-0.07% through the relative OF use change.[9]

[8] We make a simple calculation about the likely decreased amount of purchased OF application assuming all rented land is non-legitimately leased: the average amount of purchased OF applied before the policy change $\times$ the proportion of owned area. If we consider the path-dependent behavior, each unit of purchased OF applied last year would reduce the current intensity by 0.25kg. Adding together, it gives the likely reduced amount of 0.09kg/m^2 for Q2, 0.14kg/m^2 for Q3, 0.19kg/m^2 for Q4, and 0.27kg/m^2 for Q5 (see appendix D).

[9] This is a simple calculation: (1) calculate the likely change in Fratio1 based on ex-ante OF prices and the policy impact estimates; (2) compute a percent change in Fratio1; (3) multiply the coefficient of Fratio1, 0.067, by the percent change of Fratio1.

The overall relationship between tenure status and aggregated organic fertilizer application is found to be insignificant here, as opposed to what has been found in previous research [Jacoby and Mansuri, 2008, Xu et al., 2014, Gao et al., 2017, Akram et al., 2019, Li and Shen, 2021]. In table 4, self-operators apply even less organic fertilizer than those in the second and third tenancy ratio quintiles. Further analysis yields the consistent result that lower quintiles, who own more of the land they operate, are not strongly associated with higher OF application (see table A3). Considering our finding that non-legitimate contracts are prevalent across all quintiles, neither land ownership nor insecure contract discourages any type of OF application. In contrast, losing access to the subsidy through insecure contracts has detrimental effects at least on purchased OF application. However, the negative impact seems to be mitigated by farmers' willingness to purchase OF at unsubsidized rate, as the behavior of farmers in the top quintile demonstrated. Even more, the reduction in purchased OF does not entail a drop in aggregated OF, possibly due to its small share in aggregated OF and the substitution of self-supplied OF. Because each quintile contains both secure and insecure tenants, the adverse impact of both sources would be larger for insecure tenants. However, the message is the same that the impact of insecure tenure status would not be as significant as found in the previous research.

This conclusion raises the question of why the impact of insecure tenure status on OF application is insignificant in Korea. Our empirical results provide three plausible explanations. First, Korean tenant farmers face lower investment costs than tenant farmers in less mechanized and less capitalized countries. Labor-related variables, household size, and health do not show a significant impact on OF application. Our additional analysis also show that wage does not affect OF application (see appendix C). In developing countries, as Jacoby and Mansuri [2008] pointed out, labor-intensive tasks, from collecting to spreading, are the main factor that hinders tenant farmers from using OF. However, OF application is much less labor-intensive in Korea due to the prevalence of farm machines and because purchasing OF became more popular due to the subsidy program. Second, a big portion of OF benefits realizes from its initial application [Oh et al., 2014, Ali et al., 2014]. Furthermore, the organic matter in OF helps crops to use inorganic fertilizer nutrients more efficiently, as agronomic findings suggest that the combined fertilizer application achieves higher crop yield

than applying one kind only [Ayoola and Makinde, 2007, Xu et al., 2008, Siavoshi et al., 2011, Lee et al., 2021]. These are consistent with our finding that the relative use of OF has significant effects on crop revenue and that OF is a complementary good for inorganic fertilizer. Third, the risk embedded in non-legitimate contracts is not severe enough to cause eviction. Even landlords who decline to make an official rental arrangement cannot easily terminate the contracts as their lands are bound to agricultural purposes. Anecdotal evidence says that tenant farmers would rather bear the cost of losing subsidies to maintain their access to rented land. While these reasons explain the insignificant relationship between tenure status and long-term investment to some extent, they cannot be generalized to other societies or other types of long-term investment. Long-term investment with higher initial cost and a longer payback period would aggravate risks associated with insecure tenancy.

Last but not least, our finding signifies the dual aspects of the Land-to-the-Tillers principle. Despite its good intention to improve farmers' welfare by restricting ownership to operators, when this principle faces challenges to implementation, it works against tenant farmers who are the actual operators. Our study shows one mechanism through which such adverse effects could occur. Any government programs that are based on officially reported farmland size must be aware of the tenure insecurity problem. Lack of consideration of the tenure issue would adversely affect real operators, which in turn affects the economic and environmental consequences of farming.

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Appendices

A The impact of the subsidy program

A.1 Model specification

This section identifies the impacts of the subsidy program, along with other characteristics, on fertilizer use. We estimate the relationship between the subsidy and the binary dependent variable using the linear probability model presented in equation (3). We use a log-linear model with a similar structure to estimate the relationship between the subsidy and the different intensive measures of fertilizer use.

$$Y_{it} = \alpha_0 + \alpha_1 ln(Subsidy_t) + \alpha_3 ln(Prices_{it}) + \alpha_4 X_{it} + \alpha_i + \varepsilon_{it} \tag{3}$$

Y_{it} includes four dependent variables: whether or not to use purchased OF for farm i in year t, the intensity of purchased OF (kg/m^2), and the intensity of inorganic fertilizer (kg/m^2). The subsidy impact is estimated with farm fixed effects. $Subsidy_t$ indicates the likely amount of subsidized OF per area at year t. The coefficient of interest is α_1 which captures the subsidy quantity effect. Therefore, α_1 is estimated by exploiting the variation of subsidy quantity across time. Market variables ($Prices_{it}$) and farm household characteristics (X_{it}) includes the same variables as in equation (1).

A.2 Result

In table A1, the subsidy variable has positive impacts on both extensive and intensive margins of purchased organic fertilizer for both pooled OLS and farm fixed model. A 1% increase in the likely amount of subsidized quantity raises the intensity of purchased OF by 1.2% and the probability of applying purchased OF by 2%, holding other variables constant. The subsidy program has also significantly reduced the intensity of inorganic fertilizer application. Most of the farm and household characteristic variables are either statistically insignificant or small in size.

Table A1: Subsidy and Fertilizer application

	ln(POF)		WPO[LPM]		ln(IF)	
	(1)	(2)	(3)	(4)	(5)	(6)
Main variables						
Subsidy quantity	1.22***	1.27***	0.20***	0.21***	-0.11***	-0.16***
	(0.065)	(0.092)	(0.013)	(0.019)	(0.021)	(0.029)
Market variables						
OF price	-1.30***	-1.39***	-0.20***	-0.22***	0.04**	0.07***
	(0.053)	(0.059)	(0.011)	(0.012)	(0.014)	(0.013)
IF price	-0.12*	0.13**	-0.04***	0.02	-1.01***	-1.07***
	(0.047)	(0.051)	(0.009)	(0.010)	(0.016)	(0.020)
Household characteristics						
Age	0.00	-0.00	0.00	-0.00	0.00	0.00
	(0.002)	(0.010)	(0.000)	(0.002)	(0.001)	(0.004)
[EDU2]Elementary	0.00	-0.50	-0.00	-0.09	0.01	0.09
	(0.052)	(0.289)	(0.011)	(0.062)	(0.019)	(0.099)
[EDU3]Middle	0.01	-0.84*	0.00	-0.16*	0.01	0.02
	(0.060)	(0.344)	(0.012)	(0.071)	(0.023)	(0.109)
[EDU4]High	0.02	-0.79*	0.00	-0.17*	-0.03	0.02
	(0.063)	(0.370)	(0.013)	(0.078)	(0.024)	(0.130)
[EDU5]College	-0.00	-0.92	-0.01	-0.25*	0.02	0.20
	(0.105)	(0.482)	(0.021)	(0.111)	(0.039)	(0.355)
Household size	-0.00	-0.04	-0.00	-0.01	-0.00	-0.00
	(0.014)	(0.033)	(0.003)	(0.007)	(0.006)	(0.012)
Health	0.00	-0.17	-0.00	-0.03	-0.00	-0.09
	(0.148)	(0.203)	(0.030)	(0.042)	(0.055)	(0.073)
Farm characteristics						
Cultivated area	0.03*	0.04	0.01***	0.01	0.03***	0.01
	(0.012)	(0.049)	(0.003)	(0.012)	(0.005)	(0.016)
Rental rate	-0.07	0.03	-0.01	0.00	-0.01	-0.06
	(0.042)	(0.144)	(0.008)	(0.030)	(0.017)	(0.048)
Off-farm income	-0.04	-0.06	-0.01	-0.01	0.06**	0.02
	(0.048)	(0.084)	(0.010)	(0.017)	(0.020)	(0.036)
Current ratio	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Farm equipment assets	-0.00	0.00	-0.00	-0.00	-0.00	-0.00
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
Livestock value	0.00	-0.00	0.00	0.00	-0.01***	0.00
	(0.004)	(0.010)	(0.001)	(0.002)	(0.002)	(0.004)
Observations	18565	18565	18565	18565	18565	18565
Farm FE	No	Yes	No	Yes	No	Yes

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) Dependent variables are as follows: Purchased OF (POF), Whether to apply purchased OF (WPO), Inorganic fertilizer (IF). (3) Models (1), (3), and (5) control for wave and region fixed effects. Models (2), (4), and (6) control for farm fixed effects. (4) All models control for farm and household characteristics: age, sex, household size, health, education, cultivated area, off-farm income, current ratio, farm equipment asset, livestock value, inorganic and organic fertilizer prices, and tenancy ratio.

B The impact of landownership

Table A2: The impact of land ownership on OF application (Full)

	ln(AOF)			ln(POF)			WPO		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Main variables									
Tenancy ratio	-0.12	-0.30		-0.07	0.01		-0.01	-0.00	
	(0.068)	(0.203)		(0.041)	(0.161)		(0.008)	(0.033)	
Tenancy quintile 2			0.34***			0.01			0.00
			(0.094)			(0.057)			(0.012)
Tenancy quintile 3			0.29***			0.08			0.02
			(0.074)			(0.046)			(0.009)
Tenancy quintile 4			0.12			-0.03			-0.00
			(0.079)			(0.046)			(0.010)
Tenancy quintile 5			-0.04			-0.07			-0.01
			(0.077)			(0.045)			(0.009)
Market variables									
OF price	-1.06***	-0.47***	-1.05***	-2.20***	-1.09***	-2.20***	-0.34***	-0.17***	-0.34***
	(0.050)	(0.053)	(0.050)	(0.087)	(0.058)	(0.087)	(0.018)	(0.012)	(0.018)
IF price	-0.35***	0.09	-0.33***	-0.15**	0.10	-0.15**	-0.04***	0.01	-0.04***
	(0.058)	(0.069)	(0.057)	(0.052)	(0.055)	(0.052)	(0.010)	(0.012)	(0.010)
Household characteristics									
Age	0.01*	-0.09***	0.01*	0.00	0.08***	0.00	0.00	0.01***	0.00
	(0.003)	(0.017)	(0.003)	(0.002)	(0.013)	(0.002)	(0.000)	(0.002)	(0.000)
[EDU2]Elementary	-0.04	-0.47	-0.03	-0.00	-0.28	-0.01	-0.00	-0.06	-0.00
	(0.082)	(0.371)	(0.081)	(0.050)	(0.357)	(0.050)	(0.011)	(0.072)	(0.010)
[EDU3]Middle	-0.10	-0.85	-0.10	0.00	-0.32	0.00	-0.00	-0.07	-0.00
	(0.097)	(0.528)	(0.097)	(0.060)	(0.459)	(0.059)	(0.012)	(0.088)	(0.012)
[EDU4]High	-0.10	-1.55**	-0.09	0.00	0.60	0.00	-0.00	0.06	-0.00
	(0.100)	(0.523)	(0.100)	(0.063)	(0.481)	(0.063)	(0.013)	(0.093)	(0.013)
[EDU5]College	0.15	-1.27	0.17	-0.09	0.65	-0.09	-0.03	0.04	-0.03
	(0.186)	(1.558)	(0.187)	(0.104)	(0.724)	(0.104)	(0.021)	(0.141)	(0.021)
Household size	0.02	0.06	0.02	0.01	-0.07	0.01	0.00	-0.01	0.00
	(0.023)	(0.056)	(0.023)	(0.014)	(0.037)	(0.014)	(0.003)	(0.008)	(0.003)
Health	-0.22	-0.34	-0.21	-0.05	-0.20	-0.05	-0.01	-0.04	-0.01
	(0.226)	(0.317)	(0.226)	(0.142)	(0.226)	(0.142)	(0.030)	(0.046)	(0.030)
Farm characteristics									
Cultivated area	0.10***	0.05	0.09***	0.03*	0.03	0.03*	0.01**	0.01	0.01**
	(0.026)	(0.061)	(0.025)	(0.013)	(0.060)	(0.013)	(0.003)	(0.014)	(0.003)
Off-farm income	0.19*	-0.16	0.22**	-0.04	-0.09	-0.03	-0.01	-0.02	-0.01
	(0.081)	(0.147)	(0.081)	(0.047)	(0.095)	(0.047)	(0.010)	(0.020)	(0.010)
Current ratio	0.00	-0.00	0.00	-0.00	-0.00*	-0.00	-0.00	-0.00*	-0.00
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Farm equipment assets	-0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	0.00	-0.00
	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Livestock value	-0.02***	0.00	-0.03***	-0.00	-0.02	-0.00	0.00	-0.00	0.00
	(0.007)	(0.017)	(0.007)	(0.004)	(0.012)	(0.004)	(0.001)	(0.002)	(0.001)
Observations	16276	16276	16276	16276	16276	16276	16276	16276	16276
HH FE	No	Yes	No	No	Yes	No	No	Yes	No
Year FE									

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) Dependent variables are as follows: Aggregated OF (AOF), Purchased OF (POF), Whether to apply purchased OF (WPO). (3) Models (2), (5), and (8) use a farm fixed model. Other models use a pooled OLS with region-year fixed effects. (4) All models control for farm and household characteristics: age, sex, household size, health, education, cultivated area, off-farm income, current ratio, farm equipment asset, livestock value. (5) The mean tenancy ratios of each tenancy quintile are as follows: Q1 (0), Q2 (0.09), Q3 (0.31), Q4 (0.64), and Q5 (0.97).

Table A3: The impact of landownership on OF application by wave

	ln(POF)			ln(SOF)		
	W8	W9	W10	W8	W9	W10
Main variables						
Tenancy quintile 1	-0.12	0.07	0.03	-0.31	-0.57***	0.15
	(0.077)	(0.096)	(0.143)	(0.167)	(0.153)	(0.221)
Tenancy quintile 3	-0.03	0.13	0.11	-0.01	-0.26	0.36
	(0.086)	(0.102)	(0.165)	(0.172)	(0.167)	(0.236)
Tenancy quintile 4	-0.11	0.00	0.01	-0.32	-0.23	0.31
	(0.084)	(0.102)	(0.153)	(0.187)	(0.163)	(0.239)
Tenancy quintile 5	-0.16	-0.03	-0.06	-0.20	-0.52**	0.05
	(0.087)	(0.100)	(0.152)	(0.184)	(0.161)	(0.235)
Market variables						
OF price	-2.08***	-2.16***	-2.42***	1.13***	0.80***	1.23***
	(0.155)	(0.123)	(0.196)	(0.154)	(0.102)	(0.148)
IF price	0.03	-0.21**	-0.20*	-0.16	-0.38***	-0.19
	(0.083)	(0.078)	(0.095)	(0.122)	(0.089)	(0.121)
Household characteristics						
Age	-0.00	0.00	0.01	0.02**	-0.00	0.00
	(0.003)	(0.003)	(0.005)	(0.006)	(0.006)	(0.008)
[EDU2]Elementary	-0.00	-0.15	0.31**	0.02	0.08	-0.22
	(0.065)	(0.086)	(0.120)	(0.140)	(0.130)	(0.196)
[EDU3]Middle	-0.06	-0.09	0.35*	-0.01	-0.11	-0.13
	(0.075)	(0.100)	(0.143)	(0.168)	(0.155)	(0.226)
[EDU4]High	-0.09	-0.11	0.43**	-0.03	0.06	-0.37
	(0.082)	(0.106)	(0.149)	(0.173)	(0.158)	(0.228)
[EDU5]College	-0.16	-0.33*	0.55*	0.38	0.43	-0.37
	(0.125)	(0.163)	(0.261)	(0.303)	(0.315)	(0.374)
Household size	-0.01	0.02	0.02	0.03	0.01	0.05
	(0.015)	(0.025)	(0.042)	(0.034)	(0.041)	(0.067)
Health	-0.03	-0.10	0.06	-0.49	-0.04	0.23
	(0.205)	(0.224)	(0.337)	(0.403)	(0.373)	(0.520)
Farm characteristics						
Cultivated area	0.02	0.01	0.06	0.20***	0.03	0.11**
	(0.017)	(0.019)	(0.030)	(0.041)	(0.035)	(0.042)
Off-farm income	-0.06	0.02	-0.09	0.46***	0.13	0.12
	(0.060)	(0.077)	(0.122)	(0.135)	(0.129)	(0.178)
Current ratio	-0.00*	-0.00	0.00	0.00*	0.00*	0.00
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Farm equipment assets	0.00	0.00	-0.00	-0.01**	-0.00	-0.00
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
Livestock value	0.00	-0.00	0.00	-0.03*	-0.02*	-0.01
	(0.005)	(0.006)	(0.010)	(0.012)	(0.011)	(0.014)
Observations	5964	6795	3517	5964	6795	3517

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) Dependent variables are as follows: Purchased OF (POF), Self-supplied OF (SOF). (3) All the models control for region-year fixed effects. (4) All models control for farm and household characteristics: age, sex, household size, health, education, cultivated area, off-farm income, current ratio, farm equipment asset, livestock value. (5) The mean tenancy ratios of each tenancy quintile are as follows: Q1 (0), Q2 (0.09), Q3 (0.31), Q4 (0.64), and Q5 (0.97). (6) The reference group is Tenancy quintile 2.

C The impact of labor variables

We examine the relationship between labor variables and OF application based on equation (1).

Table A4: The impact of labor variables on OF application

	ln(AOF)		ln(POF)		WOF		WPO	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Main variables								
Wage	0.00	0.00	-0.00*	0.00	-0.00	0.00	-0.00**	-0.00
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age	0.01*	-0.01	0.00	0.01	0.00*	0.00	0.00	0.00
	(0.003)	(0.023)	(0.002)	(0.013)	(0.001)	(0.004)	(0.000)	(0.003)
Household size	0.01	0.02	0.01	-0.03	0.00	0.00	0.00	-0.01
	(0.023)	(0.055)	(0.014)	(0.035)	(0.004)	(0.010)	(0.003)	(0.007)
Health	-0.22	-0.32	-0.05	-0.28	-0.06	-0.06	-0.01	-0.05
	(0.226)	(0.312)	(0.142)	(0.223)	(0.040)	(0.056)	(0.030)	(0.046)
Market variables								
OF price	-1.06***	-0.56***	-2.20***	-1.34***	-0.15***	-0.08***	-0.34***	-0.21***
	(0.050)	(0.056)	(0.087)	(0.065)	(0.009)	(0.010)	(0.018)	(0.013)
IF price	-0.35***	-0.02	-0.15**	0.05	-0.07***	-0.01	-0.04***	0.00
	(0.058)	(0.070)	(0.051)	(0.056)	(0.010)	(0.012)	(0.010)	(0.012)
Farm and household characteristics								
[EDU2]Elementary	-0.04	-0.14	-0.00	-0.48	-0.00	-0.01	-0.00	-0.08
	(0.082)	(0.369)	(0.050)	(0.305)	(0.014)	(0.063)	(0.010)	(0.065)
[EDU3]Middle	-0.10	-0.30	0.01	-0.76*	-0.02	-0.02	-0.00	-0.13
	(0.097)	(0.515)	(0.059)	(0.373)	(0.017)	(0.091)	(0.012)	(0.077)
[EDU4]High	-0.10	-0.30	0.01	-0.45	-0.02	-0.02	-0.00	-0.10
	(0.100)	(0.524)	(0.063)	(0.410)	(0.017)	(0.089)	(0.013)	(0.083)
[EDU5]College	0.15	0.12	-0.08	-0.49	0.02	0.04	-0.02	-0.13
	(0.186)	(1.398)	(0.103)	(0.511)	(0.031)	(0.239)	(0.021)	(0.112)
Tenancy ratio	-0.12	-0.19	-0.07	-0.07	-0.02	-0.03	-0.01	-0.02
	(0.068)	(0.205)	(0.041)	(0.157)	(0.012)	(0.035)	(0.008)	(0.033)
Cultivated area	0.10***	0.03	0.03*	0.02	0.02***	0.02*	0.01**	0.01
	(0.026)	(0.059)	(0.013)	(0.055)	(0.005)	(0.010)	(0.003)	(0.013)
Off-farm income	0.19*	-0.15	-0.04	-0.08	0.02	-0.03	-0.01	-0.01
	(0.081)	(0.147)	(0.047)	(0.094)	(0.014)	(0.026)	(0.010)	(0.019)
Current ratio	0.00	-0.00	-0.00	-0.00	0.00*	-0.00	-0.00	-0.00
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Farm equipment assets	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	0.00
	(0.001)	(0.003)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Livestock value	-0.02***	-0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00
	(0.007)	(0.017)	(0.004)	(0.012)	(0.001)	(0.003)	(0.001)	(0.002)
Observations	16276	16276	16276	16276	16276	16276	16276	16276
Farm FE	No	Yes	No	Yes	No	Yes	No	Yes

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) Dependent variables are as follows: the intensity of aggregated OF (AOF) and purchased OF (POF), whether to apply OF (WOF) and whether to apply purchased OF (WPO). (3) The model specification follows equation (1) with additional control variable, wage. (4) Pooled OLS models control for region-year fixed effects. (5) A hourly wage is computed by dividing the total labor cost by the total working hours. The family labor cost is computed based on regional farm wage or manufacturing wage. The hired worker wage is an actual wage paid to non-family workers.

D Sample selection bias

D.1 Source of selection bias

In model 2, we restricts the sample to farmers who have used purchased OF at least once before the policy change. This selection criteria may cause some biases especially when fertilizer use decision is dependent on its past application: farmers who applied purchased OF last year may skip applying purchased OF this year because OF nutrients from last year still remain in effect. We test if farmers' fertilizer decision is dependent on their past decision. Equation (4) identifies this path dependent effect on current OF application.

$$Y_{it} = \tau_1 Y_{it-1} + \tau_2 Y_{it-2} + \tau_t + \tau_i + \varepsilon_{it} \tag{4}$$

Y_{it} represent four OF behavior measurements: the intensity of purchased OF (POF), whether to apply purchased OF (WPO), the intensity of aggregated OF (AOF), and whether to apply OF (WOF), for farm i in year t. Y_{it-1} has one year lagged value of a dependent variable, Y_{it}, for farm i. This model controls for farm and year fixed effects.

Table A5: Path dependency of fertilizer decisions

	POF		WPO		AOF		WOF	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Y(t-1)	-0.25***	-0.56***	-0.27***	-0.44***	-0.20***	-0.39***	-0.23***	-0.39***
	(0.021)	(0.024)	(0.020)	(0.022)	(0.023)	(0.028)	(0.022)	(0.031)
Y(t-2)		-0.57***		-0.28***		-0.47***		-0.28***
		(0.022)		(0.019)		(0.028)		(0.032)
Observations	2911	1877	2911	1877	2911	1877	2911	1877

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) Dependent variables are as follows: the intensity of purchased OF (POF), whether to apply purchased OF (WPO), the intensity of aggregated OF (AOF), and whether to apply OF (WOF). (3) We control for farm and year fixed effects. (4) The sample includes 18,686 farm-year units observed before the 2016 policy change. (4) Missing values of the lagged variables are dropped from the analysis.

The results in table A5 confirms the concern that past OF applications negatively affect current OF application decisions.

D.2 The impact of sample selection bias

The path dependent behavior raises the concern that the estimated level changes in OF input in table 5 could be attributed to the sample selection bias rather than the intervention effect. To address this concern, we run the same farm fixed model (equation (2)) for wave 9 to see to what extent the sample selection affects our estimates. We restrict the sample to those who have applied purchased OF before 2010 in this analysis. Table A6 shows the impact of the sample selection on application of purchased OF. In terms of WPO, the probability of using purchased OF sharply drops in the most of quintiles in 2011-12. However, the intensity of purchased OF application remained unaffected across all the quintiles.

Table A6: The impact of sample selection (Wave 9)

	POF					WPO				
	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5
Main variables										
2008	-0.08*	0.09	0.01	-0.10	-0.11	-0.11	-0.01	0.14	0.02	-0.18
	(0.037)	(0.132)	(0.028)	(0.067)	(0.059)	(0.087)	(0.134)	(0.114)	(0.125)	(0.104)
2009	0.00	0.03	0.03	-0.02	-0.03	0.01	0.06	0.21*	0.03	0.05
	(0.034)	(0.034)	(0.026)	(0.039)	(0.046)	(0.081)	(0.122)	(0.094)	(0.097)	(0.090)
2011	-0.01	-0.02	0.02	-0.06	-0.03	-0.19**	-0.13	-0.10	-0.28***	-0.12
	(0.023)	(0.041)	(0.024)	(0.042)	(0.040)	(0.059)	(0.104)	(0.066)	(0.072)	(0.068)
2012	-0.03	-0.03	-0.03	-0.09	-0.09	-0.29***	-0.15	-0.20**	-0.26***	-0.23**
	(0.029)	(0.034)	(0.019)	(0.048)	(0.044)	(0.063)	(0.114)	(0.061)	(0.074)	(0.069)
Market variables										
OF price	-0.19***	-0.13***	-0.13***	-0.17**	-0.18***	-0.25***	-0.30***	-0.23**	-0.23***	-0.39***
	(0.041)	(0.033)	(0.024)	(0.062)	(0.032)	(0.044)	(0.081)	(0.070)	(0.064)	(0.051)
IF price	0.06**	0.05	-0.01	0.06	-0.04	0.01	-0.14	0.06	0.01	-0.07
	(0.019)	(0.036)	(0.021)	(0.033)	(0.026)	(0.052)	(0.095)	(0.067)	(0.062)	(0.064)
Observations	593	231	409	411	410	593	231	409	411	410

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) The sample contains farmers who have purchased OF at least once, before 2010, in the wave 9. (3) The dependent variables are as follows: Purchased OF (POF) and whether to buy purchased OF(WPO). (5) All regressions control for farm fixed effects. (6) The mean tenancy ratios of each tenancy quintile are as follows: Q1 (0), Q2 (0.09), Q3 (0.33), Q4 (0.61), and Q5 (0.97).

E The impact of OF application on farm revenue

E.1 Model specification

This model estimates the impact of OF application on farm revenue. We use farm and year fixed effects to control for unobserved farm characteristics, e.g. farmer's managerial ability, land quality of the consistently cultivated area during observed years, and time effects such as the weather or market conditions in a particular year. Equation (5) presents the model specification[10].

$$\begin{aligned} ln(Y_{it}) = \gamma_0 + \sum_{j=1}^{6} \gamma_j ln(IP_{ijt}) + \theta_1 ln(Fratio1_{it}) + \theta_2 [ln(Fratio1_{it}) \times ln(Rent_{it})] \\ + \theta_2 ln(Fratio1_{it-1}) + \theta_3 ln(Fratio1_{it-2}) \\ + \mu X_{it} + \gamma_{FE} + \varepsilon_{it} \end{aligned} \tag{5}$$

$ln(Y_{it})$ measures crop revenue in KW/m^2 for farm i in year t. IP_{ijt} indicates farm i's expense on input j in year t. IP includes five major inputs of rice production: land, labor, fertilizer, farm equipment, pesticide, and seed. Labor costs include both family and employed labor[11]. Farm equipment costs include depreciated cost, repair and maintenance expenses, and rental fees. Fertilizer includes both inorganic and organic fertilizers. Pesticide includes both liquid and solid pesticides and herbicides. $Rent_{it}$ is measured by actual transactions between tenants and landlords for rented land (KW/m.[12] $Fratio1_{it}$ is measured by the proportion of OF expense in total fertilizer expense. We also include the lagged variable $Fratio1$ to see its long-term effects on crop revenue. The interaction between $Fratio1_{it}$ and rent is included to control for the interaction between soil fertility and OF application, as soil fertility is the most important determinant of rents [Lee, 1996]. X_it includes farm and household characteristics as in equation (5).

[10] Monetary input and output data is used instead of physical quantity for two reasons. First, physical quantities do not address the quality of inputs: e.g., land quality or different types and qualities of pesticides and fertilizers. Second, the rice production proportionally increases with its planted area. We also estimated the production function with physical quantities, which yields 0.95 of the output elasticity of planted area at the 0.001 significance level

[11] The KAPCS use regional farm hourly wage (or manufacturing wage) for family labor wage, and use actual payment for hired labor.

[12] For self-operated land rental rate, the KAPCS use the rental rate of nearby rented farmland: what is the rental rate of the land beside yours?

E.2 Result

The result shows that a 1% increase in fertilizer cost increases crop revenue by 0.03% or 0.012%, controlling for fertilizer composition (see table A7). Fratio1's estimate is significantly positive, controlling for lagged organic fertilizer inputs, and the interaction between Fratio1 and rent. The interaction effect is significant, suggesting that OF's contribution to crop revenue depends on land profitability which is captured by rent. The lagged Fratio1 is positive but insignificant, as shown in column (2). Of the other input variables, land and labor are the most important inputs. In addition, custom service and mechanization show a positive impact on crop revenue. Higher off-farm income negatively affects crop revenue in both columns (1) and (2). The financial liquidity does not affect crop revenue; it could be because most of the farmers in our sample have much higher current assets than short-term liabilities.

Table A7: Fertilize use and Crop revenue

	ln(Crop revenue)			
	(1)		(2)	
Input variables				
Land rent	0.46***	(0.02)	0.36***	(0.02)
Labor cost	0.31***	(0.01)	0.18***	(0.01)
Farm equipment cost	0.027***	(0.00)	0.0097***	(0.00)
Pesticide cost	-0.00057	(0.00)	0.0036**	(0.00)
Seed cost	0.0038***	(0.00)	0.0029***	(0.00)
Fertilizer-related variables				
Fertilizer cost	0.030***	(0.00)	0.012***	(0.00)
Fratio1	0.15***	(0.03)	0.066*	(0.03)
Fratio1 X Rent	-0.0099***	(0.00)	-0.0045*	(0.00)
Fratio1 at t-1	-0.00076	(0.00)	0.0012	(0.00)
Fratio1 at t-2	-0.00063	(0.00)	0.00095	(0.00)
Farm characteristics				
Cultivated area	0.0000065***	(0.00)	0.000016***	(0.00)
Tenancy ratio	0.037***	(0.01)	0.092***	(0.02)
Custom work	0.84***	(0.03)	0.64***	(0.04)
Mechanization	0.0074	(0.00)	0.0081*	(0.00)
Off-farm income	-0.089***	(0.01)	-0.089***	(0.01)
Current ratio	-0.000028	(0.00)	0.0000076	(0.00)
Household characteristics				
Age	-0.0021***	(0.00)	0.0025	(0.00)
Sex	0.0030	(0.01)	0.0075	(0.03)
Household size	0.0036	(0.00)	0.0049	(0.00)
Health	-0.029	(0.02)	-0.0021	(0.03)
[EDU2]Elementary	0.012	(0.01)	0.00043	(0.03)
[EDU3]Middle	0.0078	(0.01)	-0.024	(0.05)
[EDU4]High	0.023*	(0.01)	-0.0094	(0.05)
[EDU5]College	-0.011	(0.02)	-0.021	(0.09)
Observations	18686		18686	
Household FE	No		Yes	

Note: *** p<0.001, ** p<0.01, * p<0.05. (1) Standard errors in parentheses. (2) Model (1) control for region and year fixed effects and their standard errors are clustered by farm. Model (2) control for household and year-fixed effects. (4) All control variables are listed.