Fertilizer Use in China: The Role of Agricultural Support Policies

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Abstract: Using a decomposition method, this paper proposes an analytical framework to investigate the mechanisms by which agricultural support policies affect farmers' use of fertilizers in agriculture in China. The mechanisms are decomposed into "three effects" (structural, scale, and technological effects). It is found that China's agricultural support polices have significantly contributed to the increased use of agricultural fertilizers through encouraging farmers to bring more land under cultivation (the scale effect). Meanwhile, some policies have also helped reduce fertilizer consumption when farmers were motivated to increase the area of grains crops (the structural effect). The role of technological progress in affecting fertilizer consumption (the technological effect) appears to be minimal and uncertain. Compared to direct subsidies, indirect subsidies play a much greater role in affecting farmers' production decision making and are more environmentally consequential. This paper argues that some of China's agricultural support policies are not well aligned with one key objective of the country's rural policies—improving environmental sustainability. It is recommended that the government takes measures to reform agricultural support policies and to reconcile agricultural and rural policies in order to achieve sustainable rural development.

Keywords: agricultural support policies; decomposition model; direct subsidies; indirect subsidies; agrochemicals; fertilizer use; sustainable agricultural/rural development; China

1. Introduction

From the 1990s, the issues facing China's agricultural and rural sectors, which were encapsulated as sannong wenti (i.e., three issues respectively concerning agriculture, farmers, and the rural society) by researchers [1], began to attract attention from both the media and policy makers. For 15 consecutive years from 2004 to 2018, sannong wenti has been a focal point of the No. 1 Central Document—the first policy statement of the year released by the Central Committee of the Chinese Communist Party (CCP) [2] that highlights the country's policy priorities. To cope with the sannong wenti, the key policy objectives of the central government have included improving agricultural production and productivity, raising farmers' income and reducing poverty, revitalizing the countryside, and (more recently) improving environmental sustainability.

It remains a question how China, facing daunting challenges, will achieve all these goals with its agricultural and rural policies. Taking environmental sustainability as an example, the overuse of agrochemicals (chemical fertilizers and pesticides) poses a major potential threat to environmental sustainability [3]. Worldwide, the overuse of agrochemicals has become an environmental concern in agricultural production, as it leads to degradation and the consequent declining productive capacity

of natural resources and poses a great threat to ecosystems and human health [4,5]. The situation is even worse in China, the largest producer and consumer of agrochemicals in the world. With 8% of the world's total arable land, China respectively accounted for 32 and 43% of the world's total consumptions of chemical fertilizers and pesticides [6,7]. The use intensities of chemical fertilizers and pesticides are four and five times that of the world average, respectively. However, the efficiency of agrochemical use is low. In 2017, the use efficiency of fertilizers for three major grain crops—rice, corn and wheat—was only 37.8%, while the use efficiency of pesticides was only 38.8% [8]. The excessive and inefficient use of agrochemicals increases production costs. It also leads to soil pollution and the contamination of water bodies. According to China's first National Census on Pollution Sources, fertilizers and pesticides from farms are a greater source of water contamination than industrial discharges. Nonpoint source pollution from agriculture alone (not including domestic point sources of rural communities) is respectively responsible for 43.7% of the nation's chemical oxygen demand, 67.2% of phosphorus, and 57.2% of nitrogen discharges [9].

Meanwhile, chemical pesticides and fertilizers are important for sustaining and boosting agricultural production, and thus contributing to income generation. To protect farmers' income, many countries in the world have agriculture support policies (ASPs). China has also actively implemented a series of policy measures to strengthen agriculture and benefit farmers, including grain subsidies, agricultural tax relief and exemption, seed subsidies, machinery subsidies, and increased funding for rural infrastructure, etc. [10]. Without doubt, these policies provide incentives to agricultural producers to stay in farming and put in more efforts and resources to increase production and productivity. Consequently, they could potentially lead to an increase in the use of agrochemicals.

So, do ASPs affect the use of agrochemicals? If they do, how and to what extent? The purpose of this paper is to bring those questions into focus and propose some tentative answers by investigating the mechanisms by which ASPs affect the application of agrochemicals. This study aims to examine the misalignment of China's ASPs with the country's defined long-term objectives of agricultural and rural development, and to demonstrate the paradoxical nature of some of these development objectives. By doing so, this paper seeks to draw recommendations for changes to current agricultural support policies and practices in China that help achieve the policy objectives of the nation to solve its sannong wenti.

The rest of this paper is organized as follows. Section 2 presents a review of the literature on the impacts of ASPs. In Section 3, we propose an analytical framework for examining the impacts of ASPs on fertilizer use. In that section, we also develop hypotheses on how ASPs may affect farmer's agrochemical use through entailing changes in the sown area of major crops and encouraging farms to adjust the structure of their farm (optimize strategy choice) and improve agricultural productivity, especially technological growth. The empirical models and estimation results are presented and discussed in Section 4. We conclude in Section 5 by summarizing major findings and highlighting policy implications.

2. Literature Review

ASPs could have substantial economic and environmental impacts. Many studies have investigated the economic impacts of ASPs, including how the policies affect agricultural outputs and farmers' income. Some have revealed that ASPs may affect agricultural outputs through changing cropping area [11,12]. They may also induce further agricultural specialization and improve agricultural productivity [13,14]. Some agricultural subsidies directly affect farmers' income, while the latter could be further boosted by increased agricultural outputs due to subsidies [15,16].

Studies of ASPs have largely focused on developed economies, especially members of the Organization of Economic Cooperation and Development (OECD), where agricultural support measures were first introduced and have been adopted on a large scale ever since (see, for example, Mayrand [17,18]). Existing studies tend to assess the environmental impacts of an agricultural support policy from three major aspects: whether the policy encourages the conversion of environmentally

fragile or ecologically valuable land, or contributes to the slowing down or halting of such conversion; whether the policy leads to the more or less intensive use of agricultural land; and whether the policy results in changes in crop structure [19–22]. All the changes incurred by a new agriculture policy could possibly affect the amount or intensity of agrochemical use. In the rest of this section, we will provide a brief review of the literature on the environmental impacts of ASPs from the three aspects.

Firstly, ASPs may motivate farmers to expand cropping areas and to increase the use of chemical fertilizers. Often times, especially in land-constrained developing countries, farmers increase cropping areas by tapping marginal and environmentally fragile land. The purpose of many ASPs is to increase agricultural output through financing capital investment and expanding cropping area. However, many of these policies may produce negative externalities on the environment, as they encourage farmers to convert ecologically important land (such as forests, prairies and wetlands) or cultivate marginal and environmentally fragile land (such as hillsides, semi-acrid zones, or soil of extremely low fertility) for crop production. The study by Lubowski et al. [20], for instance, showed that the increases in crop insurance subsidy during 1992 and 1997 brought less productive, erosion-prone land into cultivation. The wetland affected by the subsidy increase totaled 37,000 acres in the contiguous 48 states, representing about one-fifth of the net loss (163,000 acres) in non-Federal wetland area between 1992 and 1997 [20]. To make things worse, farmers, stimulated by subsidies, tend to apply more chemical fertilizers to improve soil fertility and crop production, which further degrades the soil structure for farming.

As Runge [23] argued, input subsidies, which are commonly used in developing countries to pay farmers to increase yield, increase the returns of agricultural production and thus attract investments and resources into the sector. When there are no environmental regulations in place, or when regulations are not effectively enforced, more marginal lands may be converted into cropland. The contribution of ASPs to agricultural extensification (e.g., expanded cropping areas and increased farm size) also finds evidence in developed countries. In the U.S., direct payments, which have been used to subsidize farmers since 2002, provide incentives to keep marginally productive land in agriculture (see, for example, Adams et al. [24]; Anderson and Parkhurst [25]). Based on their study of farmers' production decisions in the U.S. during the years since the Farm Security and Rural Investment Act of 2002, O'Donoghue and Whitaker [26] found that farm subsidies changed farmers' acreage decisions. Direct payments, for instance, increased farm size by 44 to 78 acres. Gardner, et al. [27] predicted that a 50% decrease in farm program payments would result in a total cropland loss of over 89 million acres. Another study by Faber, et al. [28] showed that during 2008 and 2011, crop insurance subsidies, along with high crop prices, contributed to massive habitat losses including more than 23 million acres of grassland, shrub land and wetlands.

In addition to subsidies, other agricultural support measures may also incur changes in cropping area. In China, for instance, the abolition of agricultural tax in 2006 increased the area of wheat, rice and corn by 10, 2.2, and 2.6%, respectively. Much of the added land was newly cultivated marginal land with low fertility [29].

Nevertheless, the findings on impacts of agricultural support on cropping areas are by no means conclusive. The study by Lewandrowski [19], for example, suggested that in high-income industrialized countries, reducing government farm sector assistance would lead to increases in the amount of land in production. This might be attributable to relaxation of supply controls or due to that farmers would opt not to participate in farm programs thereby terminating the effects of supply controls [19] (p. 419). The conflicting results suggest that the environmental impacts of agricultural support can be complicated by many factors.

Secondly, agricultural support programs may drive agricultural intensification and contribute to the increased use of chemical fertilizers. In order to receive more subsidies, farmers, in addition to expanding cropping area, would make more intensive use of fertilizers, pesticides, irrigation water, and fossil fuels, to increase yields [30]. A strong positive association between agricultural support and the intensity of fertilizer use has been found to exist in OECD countries [17,18], as well as in developing

countries including China [31,32]. Based on an analysis of 40 countries, Harold and Runge [33] found that when the Producer Subsidy Estimate (PSE)—a measure of the value of transfers to producers from consumers and taxpayers resulting from a given set of agricultural policies—increased by one unit, commercial fertilizer use would increase by 15.4 kg per hectare per year. On the other hand, research found that during the 15 years after the government abolished price subsidies and input subsidies in the 1980s, the use of fertilizers and pesticides saw a significant decline in New Zealand [34]. Using a general equilibrium approach, Taheripour, Khanna, and Nelson [35] also found that, in an open economy, removing agricultural subsidies and imposing nitrogen reduction subsidies can effectively enhance welfare and reduce nitrogen pollution.

Thirdly, ASPs could affect crop diversity and agricultural inputs through altering farmland allocation and crop structure. Farming is a risky business constrained by weather, markets and other ecological, economic and technological factors that are in flux. To reduce economic and ecological risks, as well as to increase farm profitability, one option is crop diversification [36]. Naturally, farmers would allocate land to the cultivation of varieties of crops to reduce vulnerability [37]. Crop diversification, along with other measures, can help create a biologically dynamic and diverse agricultural ecosystem. A more diverse agricultural ecosystem can contribute to agroecosystem resilience and maintain soil fertility [38], which reduces the need for fertilizers, pesticides, and other agrochemicals. Nevertheless, agricultural support measures often increase producers' willingness to take the ecological risk and therefore distort their planting decisions [39].

Crop specific subsidies, for example, adversely affect crop diversification. In order to maximize profitability, farmers respond to the incentive by increasing cropland allocation to the subsidized crop(s) and reduce the cropland allocated to other crops [40]. A less diverse cropping structure reduces the resilience of the agroecosystem and increases the probability of system's suffering from adverse consequences such as crop failure, blights, and insects. It also depletes the soil's nutrients as the same crop drains the same nutrients each year. In response, farmers will increase the application of fertilizers and pesticides.

An alteration to the crop structure could create environmental impacts through other means. Because different crops have different needs for the amount and variety of nutrients and vary in their immunity against pests and diseases, changes in the crop structure could affect the total demand for fertilizers and other agrochemicals. Many studies have provided empirical support to demonstrate that agricultural support programs have impact on crop structure through affecting the sown area of crops covered by the programs. The study by Goodwin and Mishra [41], for example, revealed that the Agricultural Market Transition Act payments, which were based on historical production (base yields and acreages) of program crops and thus were considered to be a program "decoupled" from production decisions [41] (p. 73) did have an impact on farmers' production decisions. During 1998–2001, major crops in the program, such as wheat, soybean, and especially corn, saw increase in acreage. Demirdöğen, Olhan, and Chavas [42] find that agricultural support policy, especially input supports (fertilizer, fuel and soil testing subsidies), have strong effects on land allocation. Their study also confirmed the existence of significant substitution effects across crops [43], with the subsidizing of cotton having a significant negative effect on farmers' incentive to grow food crops.

The current literature provides useful insights into the impacts of agriculture support programs and policies. It also has several weaknesses that need attention. Firstly, the majority of studies have either focused on the impacts of ASPs on farmers' production decisions (and consequent changes in land use, crop structure, etc.), or on the how farmers' production decision behavior influences the use of agrochemicals. With limited exceptions [44–46], relatively few studies have explicitly examined how agricultural policies, through changing farmers' production decisions, affect the use of agrochemicals. Secondly, many current studies have analyzed only a single policy. Due to the diversity and complexity of agricultural support systems, some inconsistent or even conflicting results could be reported. For instance, Huang et al. [47] reported that direct subsidies, such as direct payments to grain producers and comprehensive direct subsidy to agriculture production materials, had no impacts on

grain production and agricultural inputs including fertilizers. Zhang et al. [48], however, argued that agricultural support policy was a very complex multidimensional system. Finding of environmental impacts based on one policy might not be used to generalize the overall environmental impacts of the agricultural support system. Lastly, even though an increasing number of studies have examined decoupled farm program payments (see, for example, Goodwin and Mishra [41]; O'Donoghue and Whitaker [26]; Brady et al. [49]; Devadoss, Gibson, and Luckstead [50]), findings from these studies, most of which are based on the experience of developed economies, cannot be readily generalized to developing countries including China. Overall, agricultural subsidies in developed countries are more prevailing and higher than in developing countries [51–53]. In China, the situation seems to be more complicated. Public ownership of rural land, (still limited) transfer of land use rights, large number of part-time farmers, etc., may affect how farmers respond to ASPs.

This study makes contributions to the literature in several ways. There seems to be a consensus that ASPs have eventual environmental impacts (including the impact on agrochemical use). However, few studies have explored how the agricultural support policies in a developing country affect the application of agrochemicals through influencing farmers' production decisions. Seeing the disjunction between the two streams of research as aforementioned, this study attempts to propose an analytical framework for evaluating the role of ASPs in influencing the use of agrochemicals, using farmers' decision-making behavior as the "mediator variable" to explain the nature of the relationship ASPs and agrochemical use. With data covering almost all major aspects of China's agriculture support (except for agricultural taxes), this study decomposes the mechanisms into "three effects" (structural, scale, and technological effects) and quantifies the impact of various agricultural support programs on agrochemical use (specifically fertilizers).

3. Research Framework and Hypotheses

In this study, farmers in China were treated as rational economic agents, or rational men or women. The classical notion of the rational man, which has also been a contested concept for a long time, refers to an individual who makes decisions that allow him to realize maximum utility or profit. We believe that the "rational man" assumption (or analogy) is justified here. The vast majority of farmers in China are small farmers. As Schultz [54] argued, small farmers are rational economic agents who make efficient farm decisions (also see Ellis and Biggs [55]). In the production process, farmers attempt to improve agricultural output by increasing fertilizer use until the marginal input cost of applying more fertilizers becomes equal to or higher than the marginal output revenue (based on their experience). The benefits, or "positive externalities", brought by various agricultural support policies, artificially lower the marginal input cost of farming while raising its marginal output, and inspire farmers to increase inputs (including fertilizers). Under this circumstance, the "rational" behavior of individual farmers may lead to "irrational" results, causing more excessive use of fertilizers.

Under this "rational man" assumption, ASPs affect agrochemical use, directly or indirectly, through influencing farmers' expected income from farming and thus changing their production decisions. To help understand the mechanisms by which ASPs affect farmers' agrochemical use, we propose an analytical framework to untangle the relationship between ASPs, farmer's decision making, and agrochemical uses (Figure 1). Inspired by the effect decomposition model used in Grossman and Krueger [56], and Vilas-Ghiso and Liverman [57], we introduce "three effects" in the model: the scale effect, structural effect and technological effect.

More specifically, the existence or introduction of ASPs is likely to increase farmers' expected income, while the latter is determined by total output and the prices of agricultural products. Farmers could increase yield through expanding cropping area and/or improving productivity. They respond to the prices of agricultural commodities by growing more crops that are most profitable, including high cash-value crops, rising-price crops, or crops that receive subsidies. Expansion in agricultural production often brings additional marginal land under cultivation, producing what we call "scale effect" (Figure 1), meaning that the expanded scale of agricultural production will increase the

demand for agrochemicals. In particular, the newly added cropland tends to be less fertile and thus requires farmers to apply more fertilizers, pesticides, and other chemical inputs to raise yields. In order to improve land productivity, farmers would make more intensive use of agricultural inputs. The implication of the intensification of agricultural inputs is twofold. On the one hand, it may result in the excessive use of agrochemicals; on the other hand, the adoption and widespread use of modern technologies and farm equipment may substitute the demand for other input, including agrochemicals. In other words, the intensification of agricultural inputs may have conflicting effects on agrochemical use ("technological effect"). In response to the changing prices of agricultural commodities and availability of government subsidies, farmers are likely to reallocating planting areas among crops and adjust the use of agricultural inputs. As discussed previously, restructuring of crop pattern may lead to field-crop specialization and reduce crop diversity, losing the ecological benefits associated with crop intercropping or crop rotation (e.g., maintaining soil fertility) and driving up the demand for certain nutrients in the soil. Meanwhile, as different crops have different needs for the amount and variety of nutrients and vary in their immunity against pests and diseases, changes in the crop structure on a large scale may affect the total demand for agrochemicals. We call the impacts on agrochemical use incurred by changing crop structure the "structural effect".
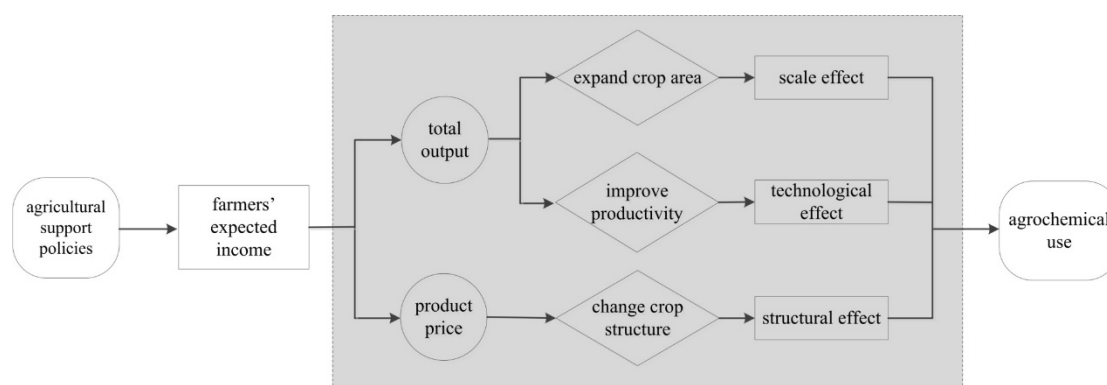
Figure 1. How agricultural support policies affect agrochemical use—an analytical framework (the shaded area represents a "black box" that needs to be opened).

Under the assumption that farmers are rational economic agents maximizing profits, we developed a profit function to illustrate the theoretical foundation of the analytical framework.

$$R = \sum f(l(Z_i, \overline{X_i}), \phi(S_i, P_i)) + Z - (\sum g(h(Z_{fer}, \overline{X_{fer}}), M_i) + \varepsilon) \tag{1}$$

where R stands for the amount of profits that farmers receive in agricultural production (unit yuan); $\overline{X_i}$ and $\overline{X_{fer}}$, respectively, represent the average market price of agricultural product i and agricultural fertilizer (unit yuan); Z_i and Z_{fer} respectively represent the amount of subsidies that crop i receives and the fertilizer receives (unit yuan); M_i refers to the amount of fertilizer that crop i uses in total (unit ton). Farmer's profit is jointly determined by farming scale (S, unit hectare), price factors (Z_i and X_i) that affect crop structure, as well as productivity (P_i, %).

Guided by this framework, the study evaluates the impacts of ASPs on fertilizer use in China, following a two-stage process: first we examine how ASPs affect farmers' production decision-making, and then we assess how the "three effects", or the three production decisions made by farmers, influence fertilizer use. Consistent with the underlying logic of each stage, we develop hypotheses concerning the relationships between policies, decision-making behavior, and fertilizer use, and test these hypotheses to determine which are best supported.

3.1. Hypotheses for Stage One

The study covers the period 2002–2015, from the year after China joined the World Trade Organization (WTO) in 2001, to the year of most recent data available when the research was conducted. Since 2002, China's agriculture policy has undergone some fundamental changes. With ambitious reductions and subsequent elimination of agricultural taxes and fees as well as the introduction of various subsidies to farmers, China has recently experienced a transition from taxing to subsidizing farmers. A new agricultural support system that is centered on price protection and direct subsidies has been created in China. The major agricultural support measures adopted in recent years are summarized in Table 1.

Table 1. Major Agricultural Support Policies in China 2002–2016.

OECD PSE Classification	Policy Grouping in China	Agricultural Support Policies *
Indirect Agricultural Subsidies	Price Protection	• Protection price (late 1990s–2004) • Minimum (or guaranteed) purchase price; temporary purchase and storage of commodity reserves (2004–2016) • Target purchase price (2016)
	Agricultural Tax Reduction	• Experiment of agricultural tax reform (2000–2004) • Provinces started eliminating agricultural taxes and fees (2004–2006) • Agricultural taxes and fees eliminated nationwide (2006)
Direct Agricultural Subsidies	"Four Agricultural Subsidies"	• Seed subsidies (2002) • Direct payments to grain producers (2004) • Machinery subsidies (2004) • General (or comprehensive) agricultural input subsidy (2006)

* For a given policy or measure, the number in the parenthesis refers to the period of implementation or the year of introduction.

Figure 2, which was constructed using the 2000 consumer price index as the base (=100), shows that agricultural subsidies (both direct and indirect) for the five major types of crops—grain (rice, wheat and corn), cotton, vegetables, oil crops (oilseed rape and peanut), and sugar crops (sugarcane only)—have risen quickly since 2002. During 2007–2008, the "global food crisis" drove the grain price on the world market to an extremely high level amidst the global financial crisis [6,58]. Due to the tight government control, grain price in China was much lower than that on the global market. As a result, the value of indirect agricultural support, which mainly targeted grain production, was abnormally low (negative). A similar but less severe situation occurred in 2011. Meanwhile, the total sown area of farm crops in China increased by 7.6% during 2002–2015—while, for many years prior to 2002, it largely remained stagnant and declined by 0.69% during 1998–2002.

As such, we hypothesize:

Hypothesis 1. *Agricultural subsidies encourage farmers to increase cropping area.*

During 2002–2015, the sown areas of the five major types of subsidized crops (Figure 3), as well as their percentages of total sown area of farm crops (Figure 4), experienced noticeable changes. The total sown area of the five types of subsidized crops increased by nearly 20 percent (19.8%). In total, these subsidized crops accounted for 80.5% of the total sown area of all farm crops in 2015, a noticeable jump from 72.3% in 2002. Grain crops, vegetables, oil crops and sugar crops saw an increase of 20.5,

26.8, 16.3, and 14.9% in sown area, respectively; the sown area of cotton decreased by 9.2%. Grain crops and vegetables, in particular, increased their share in the total sown area from 49.6 to 55.6%, and from 11.2 to 13.2%, respectively (Figure 4).
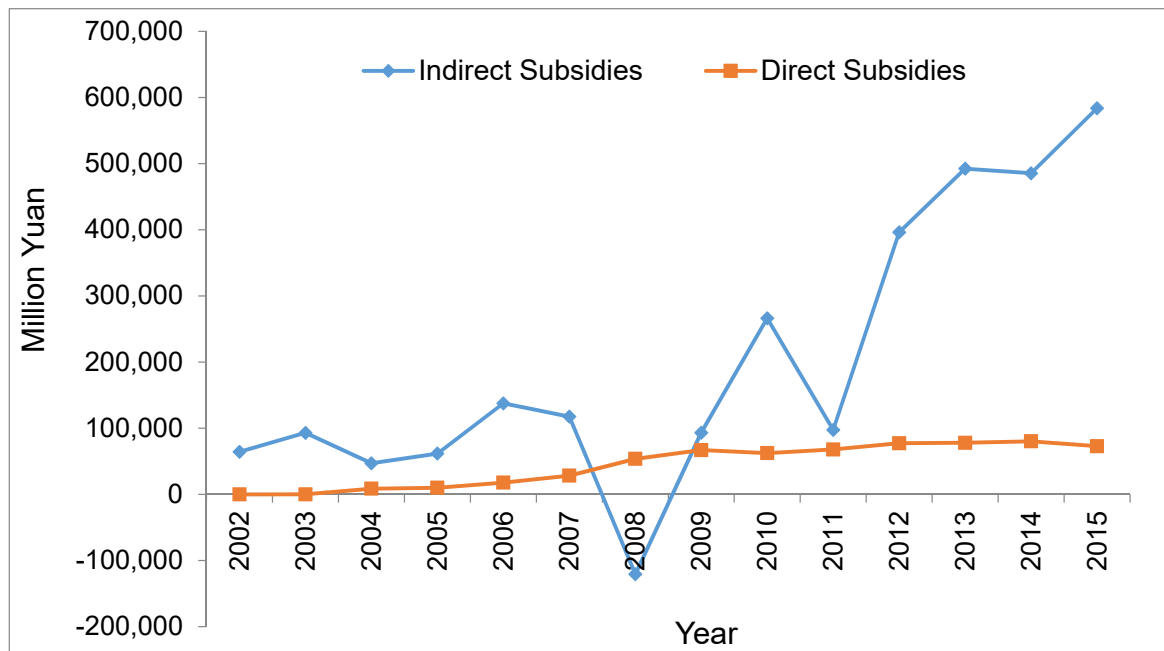

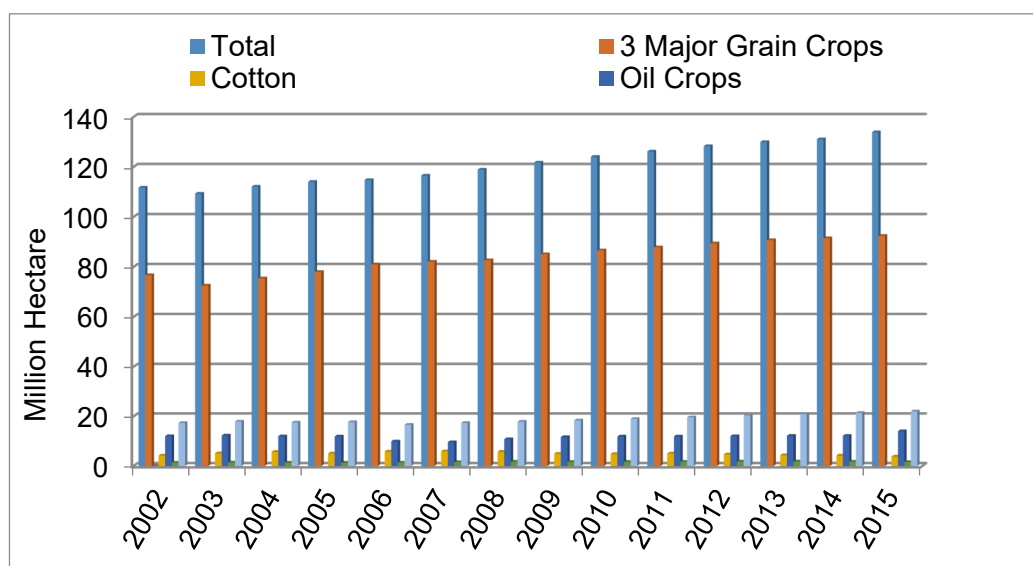**Figure 2.** Subsidies for Major Crops in China, 2002–2015.

Figure 3. Area of the Five Major Types of Crops Covered by Subsidies, 2002–2015.

Therefore, we hypothesize:

Hypothesis 2. *Agricultural subsidies encourage farmers to grow more subsidized crops, and thus change the crop structure.*

Scholars often use the Cobb–Douglas (CD) production function to estimate total factor productivity (TFP) and technological progress. In a standard growth accounting framework, Cobb–Douglas-Kaldor paradigm explains TFP growth based on Hicks-neutral technological progress. Nonetheless, considering that technological progress is factor-biased [59–61], this study relaxed the Hicks-neutral technological

progress hypothesis in the Cobb–Douglas–Kaldor paradigm. An expanded CD production function with elastic substitution for factors (i.e., factor-biased *technological* change) was introduced to estimate agricultural technological progress in China, which is expressed as

$$Y = e^{\sigma_0 + \sigma_1 t} K^{\alpha_0 + \alpha_1 t} L^{\beta_0 + \beta_1 t} S^{\gamma_0 + \gamma_1 t} e^{\mu} \tag{2}$$

where Y represents agricultural output; K, L, S respectively represents capital, labor and land inputs; $e^{\sigma_0 + \sigma_1 t}$ represents the agricultural technological growth rate; and e^{μ} is a random error term, which has a multiplicative relationship with other variables. The parameters β, α, σ, and γ represent output elasticity of technology, capital, labor and land, respectively, while μ is random error. β_0 and $\beta_1 t$ respectively represent the part of the elasticity of labor output that does not change over time and the part that changes over time. The expression $\beta_0 + \beta_1 t$ was used to denote the elasticity of labor that varies over time, making this modified version of the CD function from the general CD function with constant elasticity. Other expressions ($\sigma_0 + \sigma_1 t$, $\alpha_0 + \alpha_1 t$, $\gamma_0 + \gamma_1 t$) were used for same reason.
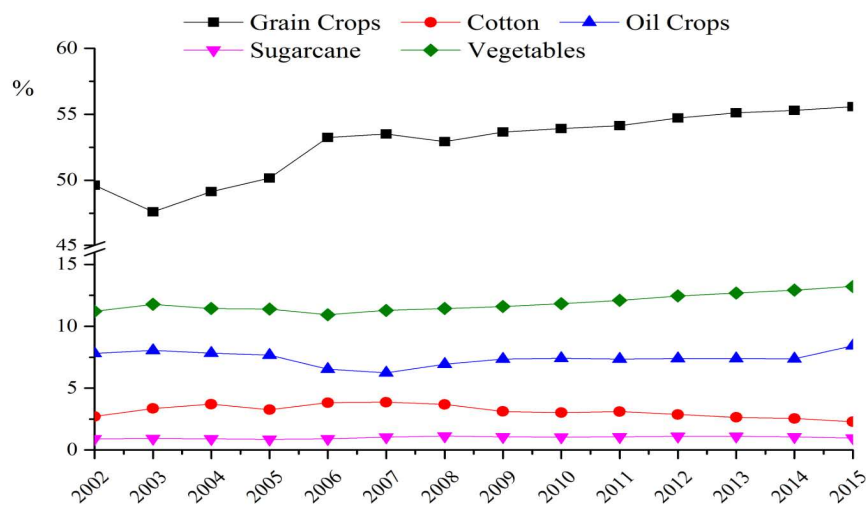

Figure 4. Percentage of the Five Subsidized Crops in the Total Sown Area.

It found that during 2002–2015, the agricultural technological growth rate improved by 14.6, or 1.04% annually. During 1998–2002, however, the annual growth rate was less than 0.8%.

Thus, we hypothesize:

Hypothesis 3. *Agricultural subsidies encourage farmers to improve agricultural technological progress.*

3.2. Hypotheses for Stage Two

During 2002–2015, chemical fertilizer consumption in agriculture increased by nearly 40 percent (Figure 5). Corresponding to Hypotheses 1–3 generated in Stage One, we propose three hypotheses for Stage Two according to the "three effects".

Generally speaking, fertilizer consumption increases when more land is brought under cultivation. Therefore, we hypothesize:

Hypothesis 4. *The scale effect contributes to the increased use of fertilizers in China.*

Crops differ from each other in their need for fertilizers (Figure 6). Changes crop structure, including the changes in the sown areas of the five major types of subsidized crops (Figures 3 and 4) will likely change the total demand for fertilizers. In China, the central government, out of the concern about food security, has maintained grain production as a priority in agricultural development. This policy and the subsidies it has rolled out help improve the economic return of grain production,

and motivate farmers to devote land to grain crops, which would otherwise be used for growing cash crops. Overall, grain crops have lower demand for fertilizers than other crops (Figure 6).
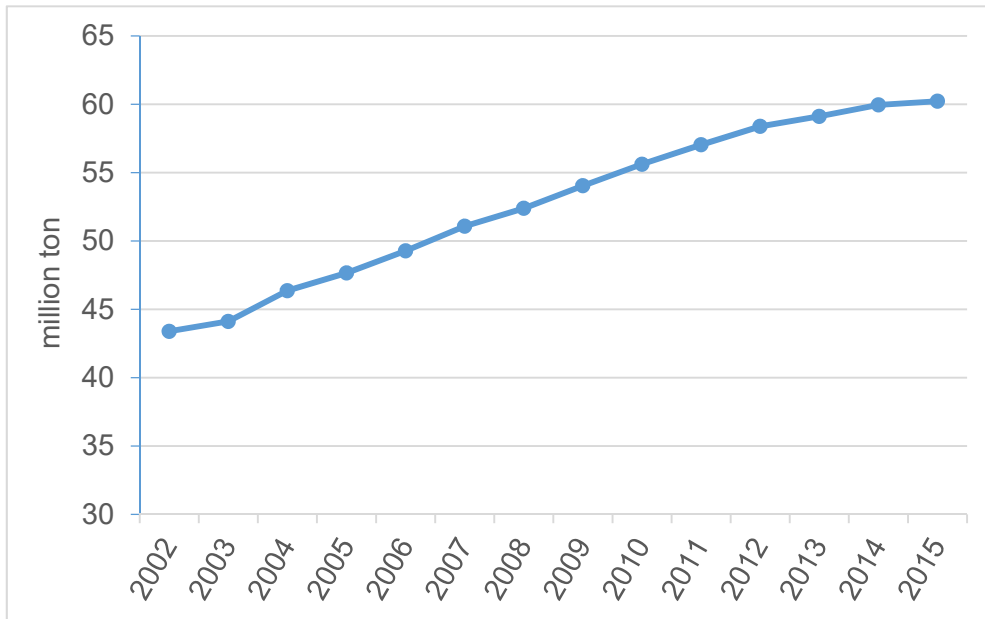

Figure 5. Fertilizer Use in China's Agriculture, 2002–2015.
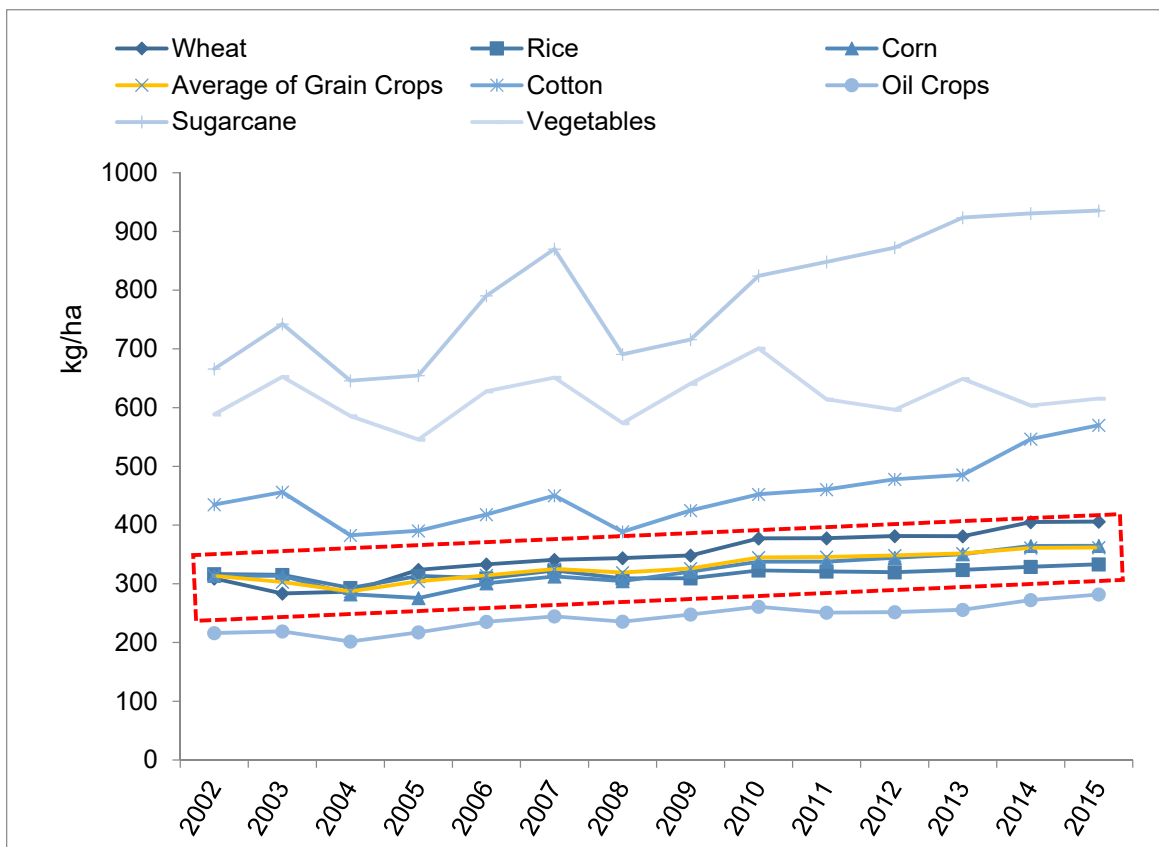

Figure 6. Consumption Intensity of Major Crops Covered by Subsidies, 2002–2015.

As such, we hypothesize:

Hypothesis 5. *The structural effect reduces fertilizer consumption.*

Progress in agricultural technology may help reduce the demand for chemical fertilizers-. Modern technology, such as soil testing and formula fertilization, improves the absorption of nutrients in the soil, and thus can help reduce fertilizer need. Deep moldboard ploughing, as another example, can treat crop residues and incorporate them into the soil as a source of nutrients and organic matter, increasing soil quality and reducing the need for artificial fertilizers. On the other hand, with technological progress, new fertilizers (and to a larger extent new pesticides and herbicides) are be used as a substitute for labor inputs, like what happened in developed countries during 1950s–1970s [62,63]. Therefore, it is difficult to estimate the overall impacts of agricultural technology on fertilizer use.

Thus, we hypothesize:

Hypothesis 6. *The impacts of technological effect on fertilizer use is uncertain.*

4. Empirical Tests and Results

4.1. Data and Empirical Models

Following the analytical framework outlined in the previous section, this section presents the results of hypothesis tests. For the variables selected in the empirical analysis (see later discussions in the section), data were collected from a variety of sources. The data used to measure China's indirect agricultural support (price supports, agricultural taxes) were compiled from the OECD Producer and Consumer Support Estimates (PCSE) database (market price support data), while data on direct agricultural support (the "four subsidies"—see Table 1) were collected or compiled from the websites of the Ministry of Finance and the National Bureau of Statistics, as well as various government documents. Data for the agricultural technological growth rate was estimated using a Cobb–Douglas production function with elastic substitution for factors. Other data were collected from China Rural Statistical Yearbook, China Statistical Yearbook, China Agricultural Yearbook, and the Compilation of Cost-benefit Data of Agricultural Products of various years during 2003–2016.

Similar to the process of hypothesis formation, the empirical testing in this section also follows a two-stage process: empirical testing of the influence of ASPs on farmers' decision making in Stage One, and empirical testing of the impact of farmers' production decisions on fertilizer use in Stage Two. Methodologically, considering the good continuity of data, this research, in reference to previous studies (see, for example, Wang and Yang [51]; Zhang and Ren [52]; Qian and Mu [53]), used time series regression models to empirically test the hypotheses.

Agricultural production displays considerable path dependency (Besser and Mann 2015). The level of many production variables, such as agricultural subsidies, planting area, crop structure, and the technological growth rate, is affected by the level of previous year(s). Considering that, this paper used a linear time-series regression model with lagged dependent variables. Given the relatively small sample size, a first-order autoregressive method was used. Meanwhile, in order to minimize endogeneity problems, we lagged all the explanatory variables.

4.1.1. Modeling the Scale Effect of Agricultural Support

As discussed previously, many factors influence the scale of farming. Similar to O'Donoghue and Whitaker [26], as well as Wang and Yang [64], this study used crop sown area as the dependent (or response) variable. The core independent (or explanatory) variables examined in this study to test Hypothesis 1–3 included direct agricultural subsidies of the previous year (DAS_{t-1}) and indirect agricultural subsidies of the previous year ($IDAS_{t-1}$). Some control variables were also included to ensure the accuracy of estimates of the influence, including sown area of the previous year (S_{t-1}), agricultural product price index of the previous year ($PIAP_{t-1}$), and cropping income as a percentage of total income ($CI_{t-1}\%$). Three models were run by varying the explanatory variable(s) included. The first model tested the overall effect of agricultural subsidies (AS_{t-1}) by combining DAS_{t-1} and

$IDAS_{t-1}$, whereas the second and third models only considered direct subsidies (DAS_{t-1}) and indirect subsidies ($IDAS_{t-1}$), respectively. The expressions of the model are as follows:

Model 1:

$$S_t = \alpha_1 S_{t-1} + \alpha_2 AS_{t-1} + \alpha_3 \ln(PIAP_{t-1}) + \alpha_4 CI_{t-1} + \varepsilon_t \tag{3}$$

Model 2:

$$S_t = \alpha_1 S_{t-1} + \alpha_2 DAS_{t-1} + \alpha_3 \ln(PIAP_{t-1}) + \alpha_4 CI_{t-1} + \varepsilon_t \tag{4}$$

Model 3:

$$S_t = \alpha_1 S_{t-1} + \alpha_2 IDAS_{t-1} + \alpha_3 \ln(PIAP_{t-1}) + \alpha_4 CI_{t-1} + \varepsilon_t \tag{5}$$

4.1.2. Modeling the Structural Effect of Agricultural Support

The aforementioned five major types of crops (grain crops, cotton, vegetables, oil crops, and sugar crops) receive the lion's share of subsidies in China. Their sown area as the percentage of the country's total crop area was used as the dependent variable ($PCAP_t$). Based on Zhang and Ren [65], and Ge and Zhou [66], etc., the study identified the following attributes of each crop in the previous year as control variables: the sown area as a percentage of the total sown area ($PART_{t-1}$), product price index ($VAPI_{t-1}$), yield per hectare (YPU_t), and production cost per unit of land (VC_{t-1}). DAS_{t-1} and $IDAS_{t-1}$ remained as the core explanatory variables. The expressions of the model are as follows:

Model 1:

$$PCAP_t = \alpha_1 PCAP_{t-1} + \alpha_2 AS_{t-1} + \alpha_3 VAPI_{t-1} + \alpha_4 YPU_{t-1} + \alpha_5 VC_{t-1} + \varepsilon_t \tag{6}$$

Model 2:

$$PCAP_t = \alpha_1 PCAP_{t-1} + \alpha_2 IDAS_{t-1} + \alpha_3 VAPI_{t-1} + \alpha_4 YPU_{t-1} + \alpha_5 VC_{t-1} + \varepsilon_t \tag{7}$$

Model 3:

$$PCAP_t = \alpha_1 PCAP_{t-1} + \alpha_2 DAS_{t-1} + \alpha_3 VAPI_{t-1} + \alpha_4 YPU_{t-1} + \alpha_5 VC_{t-1} + \varepsilon_t \tag{8}$$

4.1.3. Modeling the Technological Effect of Agricultural Support

In this part of the test, China's agricultural technological growth rate ($RATP_t$), which measures the change in agricultural technological level, served as the dependent variable. Similar to Qian and Mu [67], Gu and Ji [68], etc., the agricultural technological growth rate of the previous year ($RATP_{t-1}$) was chosen as the control variable. DAS_{t-1} and $IDAS_{t-1}$ were still the core explanatory variables. The expressions of the model are as follows:

Model 1:

$$RATP_t = \alpha_1 RATP_{t-1} + \alpha_2 AS_{t-1} + \varepsilon_t \tag{9}$$

Model 2:

$$RATP_t = \alpha_1 RATP_{t-1} + \alpha_2 DAS_{t-1} + \varepsilon_t \tag{10}$$

Model 3:

$$RATP_t = \alpha_1 RATP_{t-1} + \alpha_2 IDAS_{t-1} + \varepsilon_t \tag{11}$$

For all the above models, an augmented Dickey–Fuller unit root test was performed. At the 10% significance level, each of the variable series rejected the unit root null hypothesis. Meanwhile, the results of the Durbin–Waston correlation test for the random error term ε_t suggests that there is no autocorrelation. Summary statistics of the data used in this study are presented in Table 2.

Table 2. Descriptive Statistics of Variables.

	Unit	N	Min	Max	Mean	Std.
AFU_t	Million tons	14	4339.39	6022.60	5276.27	589.82
$IDAS_t$	Million yuan	14	−188,212.75	537,979.02	183,626.92	192,450.75
DAS_t	Million yuan	14	101.94	97,984.86	56,993.02	38,121.54
S_t	1000 hectares	14	152,149.00	166,374.00	158,528.93	5167.92
$PIAP_t$	dimensionless number	14	100.00	226.23	157.69	45.63
$AFPI_t$	dimensionless number	14	80.78	158.84	124.00	27.66
CI_t	%	14	1589.82	3434.87	2346.93	611.80

4.2. Influence of Agricultural Support Policies on Farmers' Decision Making

In this subsection, we present the results of the empirical testing of the influence of ASPs on farmers' decision making (i.e., Hypotheses 1–3, or the "three effects" of agricultural subsidies).

4.2.1. The Scale Effect of Agriculture Support

The testing results for the scale effect of ASPs are presented in Table 3. As the results of Model 1 show, overall, agricultural subsidies had significant and positive impacts on cropping area. A subsidy increase of one million yuan could possibly expand total cropping area by 47 hectares. This finding is consistent with the study by O'Donoghue and Whitaker [26] for the United States, but the coefficient in this analysis was much smaller. One possible reason is that farm size is much greater in the United States and the amount of farmland per farmer is much larger, which amplify the effect of ASPs.

Table 3. Testing of the Scale Effect of Agricultural Support.

Variable		Model 1	Model 2	Model 3
DAS_{t-1}	AS_{t-1}	0.0471 * (1.786)	0.0018 (1.265)	
$IDAS_{t-1}$				0.0626 ** (2.453)
S_{t-1}		0.8013 *** (14.867)	0.9262 *** (3.431)	0.8405 *** (3.137)
Ln ($PIAP_{t-1}$)		17.3046 (0.761)	25.3335 * (1.964)	19.2081 * (1.822)
$CI\%_t$		101.0058 ** (2.614)	168.020 ** (2.847)	149.0710 ** (2.473)
C		113.7206 ** (2.874)	169.1352 ** (2.812)	87.4048 ** (2.512)
		$R^2 = 0.871$	$R^2 = 0.791$	$R^2 = 0.825$

*, **, *** denote statistical significance levels at 10%, 5%, and 1%, respectively; Figures in parentheses are standard errors (t values).

To further understand the scale effect of different types of subsidies, two additional models (Models 2 and 3) were run. As shown in Table 3, with other factors being equal, indirect subsidies ($IDAS_{t-1}$) significantly increased cropping area. When indirect subsidies increased by one million yuan, they potentially contribute to an increase of 63 hectares in total sown area. The scale effect of direct subsidies, however, was not significant. This finding could be explained by the fact that China's direct agricultural subsidies are, in essence, decoupled subsidies [69], which are offered based on the amount of farmland allocated to each household have nothing to do with output or product price. By design, directed subsidy measures (Table 1) in China, such as seed subsidies, direct payments to grain producers, and general agricultural input subsidy, are coupled measures as they are supposed to be tied to the actual sown area of certain crops. In practice, these subsidies are distributed ubiquitously based on the amount of farmland or the number of people each household has [69], and thus become de facto decoupled measures. Surveys by Huang et al. [48], Huang, Wang, and Rozelle [70] also revealed that these subsidies had little or no relationship to farmers' production decisions.

The coefficients of control variables are as expected. The positive and significant coefficients of S_{t-1}, $PIAP_{t-1}$, $CI_t\%$ suggested the path-dependent nature of production decision making and farmers'

sensitivity to agricultural product price and production cost, which have also been reported in other contexts [71,72].

4.2.2. The Structural Effect of Agriculture Support

Model 1 results show (Table 4) that, overall, agricultural subsidies had significantly positive but relatively small impact on the area percentage of the five major types of crops. With other factoring remaining the same, an increase of one million yuan in subsidy would possibly increase the area of the five crops by 0.002 percent. Nevertheless, direct and indirect subsidies differed in their contributions. While the contribution of indirect subsidies was significant, direct subsidies had basically no influence on the area of the crops. Once again, this was probably due to that direct subsidies are *de facto* decoupled subsidies (except for machinery subsidies). As in many cases such subsidies are predetermined (based on the fixed amount of farmland of each household, etc.), they do not provide much motivation to farmers to plant particular crops.

Table 4. Testing of the Structural Effect of Agricultural Support.

Variable		Model 1	Model 2	Model 3
DAS_{t-1}	AS_{t-1}	0.0020 * (1.856)		0.0000 (0.413)
$IDAS_{t-1}$			0.0028 ** (2.224)	
$PART_{t-1}$		0.8143 *** (3.616)	0.8751 *** (4.131)	0.9090 *** (5.370)
$VAPI_{t-1}$		0.0094 ** (2.235)	0.0111 *** (2.456)	0.0267 *** (2.962)
YPU_t		0.0373 (0.011)	0.0504 (0.178)	0.0408 (0.151)
VC_{t-1}		−0.0282 * (−1.762)	−0.0341 ** (−2.145)	−0.0610 *** (−2.715)
C		0.9792 * (1.816)	0.5461 ** (2.441)	0.4066 ** (2.114)
		$R^2 = 0.713$	$R^2 = 0.648$	$R^2 = 0.552$

*, **, *** denote statistical significance levels at 10%, 5%, and 1%, respectively; Figures in parentheses are standard errors (t values).

Similar to the control variables in the testing of scale effect, control variables here also reflected the path-dependent nature of production decision making ($PART_{t-1}$) or farmers' sensitivity to agricultural product price ($VAPI_{t-1}$) and production cost (VC_{t-1}).

In general, the results of the empirical test are consistent with previous findings that farmers respond to agricultural support measures by adjusting crop structure and increasing the area of subsidized crops [73].

4.2.3. The Technological Effect of Agriculture Support

The testing results presented in Table 5 show that, together, agricultural subsidies have a small and insignificant impact on technological progress (column 2). When DAS_t and $IDAS_{t-1}$ were tested separately, however, the results show that the impact of indirect subsidies became significant, whereas DAS_t remained very weak and insignificant. This finding is consistent with the study by Serra et al. [74]. The reason was likely that indirect subsidies, which are largely coupled subsidies in China, motivated farmers to improve production (and thus receive more subsidies) through investing more in agricultural inputs (including technological inputs) and improving land productivity. The control variable $RATP_{t-1}$ was positive and significant, suggesting that agricultural technological progress also displayed a path-dependent trajectory.

Overall, the results confirm what McCloud and Kumbhakar [75] found that agricultural subsidies have positive impacts on technical efficiency and improve productivity. They also confirm some previous findings that agricultural subsidies improved productivity of some major crops, such as corn [76] and wheat [77], in China.

To summarize, the empirical tests at the first stage show that China's agriculture support policies changed farmers' production decisions and encouraged them to expand production, adjust crop

structure, and improve productivity, producing significant scale effect and structural effect as well as insignificant technological effect.

Table 5. Testing of the Technological Effect of Agricultural Support.

Variable		Model 1	Model 2	Model 3
DAS_{t-1} $IDAS_{t-1}$	AS_{t-1}	0.0017 (1.142)	0.0006 (0.261)	0.0022 * (1.776)
$RATP_{t-1}$		0.7294 *** (5.501)	0.8456 *** (6.002)	0.797 *** (5.426)
C		2.2153 ** (2.441)	4.5661 *** (3.267)	6.0207 *** (2.810)
		$R^2 = 0.400$	$R^2 = 0.307$	$R^2 = 0.335$

*, **, *** denote statistical significance levels at 10%, 5%, and 1%, respectively; Figures in parentheses are standard errors (t values).

4.3. Impacts of Farmers' Production Decisions on Fertilizer Use

At this stage, we test the impacts of farmers' production decisions on fertilizer use through the "three effects" (i.e., Hypotheses 4–6).

In the tests, the dependent variable was agricultural fertilizer use (AFU_t). S_t, $PCAP_t$ and $RATP_t$, previously used as dependent variables to test Hypotheses 1–3 respectively, served as the core independent variables in testing Hypotheses 4–6. Based on the theoretical discussions in the hypothesis section and data availability, as well as in reference to previous studies [43,66], several control variables were incorporated in the model, including fertilizer price index ($AFPI_t$), comprehensive price index of crop products ($CPAPI_t$), and adoption of the soil testing and formula fertilization technology (D_t). D_t is a dummy variable. The soil testing and formula fertilization technology was introduced in China in 2005 and has been promoted since then. Therefore, D_t was assigned a value 1 for the years before 2005 and a value 0 for 2005 and years after.

The test results, which are presented in Table 6, show that the scale effect, or S_t, had strong positive stimulating effect on fertilizer use. On the other hand, $PCAP_t$, which represented the structural effect, tended to deter increase in fertilizer use. The impact of $RATP_t$ (technological effect) can largely be ignored. In other words, the test results supported Hypotheses 4–6. They also confirmed the existence and relative strength of the "three effects", i.e., the channels through which ASPs affect the application of agrochemicals.

Table 6. Testing of the Impacts of the "Three Effects" on Fertilizer Use.

| Variable	AFU_t
S_t	0.0486 *** (10.612)
$PCAP_t$	−0.4415 ** (−2.135)
$RATP_t$	−0.0002 (−0.323)
$AFPI_t$	−0.0664 * (−1.798)
$CPAPI_t$	0.5930 *** (8.012)
D_t	−0.0583 ** (−3.144)
C	23.1622 * (1.966)
	$R^2 = 0.715$

*, **, *** denote statistical significance levels at 10%, 5%, and 1%, respectively; Figures in parentheses are standard errors (t values).

In line with the literature, the results of this part of the analysis find support in existing studies. The positive stimulating effect of S_t, on fertilizer use during 2002–2015, for example, paralleled the findings in Xu [78] that prior to 2015 agricultural fertilizer use in China increased along with increase in cropping area but they both started to decline thereafter. The results of $PCAP_t$ are consistent with the literature that change in crop structure results in change in fertilizer consumption [79]. Regression results revealed that $PCAP_t$ tended to deter the increase in fertilizer use. This had largely to do with

substantial increase in grain crops and (to a lesser extent) oil crops, which are less fertilizer demanding than other crops such as vegetables. It also had to do the decline in the cultivated area of cotton and very slow growth of sugarcane, as both crops have high fertilizer requirements.

$RATP_t$ showed minimal and negative impact on fertilizer use, indicating that the substitution effect of technology for fertilizer has not become apparent. The reason might be that on the one hand, the agricultural technological growth rate was still relatively low during 2002–2015. Compared with the other two core explanatory variables, its effect in explaining the dependent variable was much weaker. On the other hand, due to the "highly distorted, fragmented farmland management" [80,81], modern practice of agricultural management and new technology are difficult to be adopted at low cost [82]. Finally, $CPAPI_t$ was significantly positively associated with AFU_t, suggesting that price mechanism still played important role in affecting production inputs. D_t was significantly negatively associated with AFU_t, indicating that the soil testing and formula fertilization technology may affectively reduce the demand for fertilizers [83].

To summarize, the results of the empirical tests for the two stages show that all the hypotheses proposed in the previous sections were supported. Figure 7 provides a visual illustration that elucidates the idea of examining the impact of ASPs on fertilizer use by decomposing it into "three effects" (as proposed in the analytical framework). Some major results from Tables 3–6 were also included in graph. Based on the results of empirical tests for the two stages, it was found that China's ASPs significantly increased fertilizer use in China (with a contribution coefficient 0.049), through increasing total crop area (contribution coefficient 0.047) (Figure 7). Fortunately, this effect was somehow offset by another effect, structural effect. Agricultural support significantly improved the sown areas of the five major types of subsidized crops (especially less fertilizer-demanding grain crops) and their percentages among the total sown area of farm crops (contribution coefficient 0.002), and consequently helped reduce fertilizer consumption (contribution coefficient −0.442). Although ASPs appeared to play a positive role in improving agricultural productivity, that contribution did not translate into impacts on fertilizer consumption. Overall, technological progress generated little impact on fertilizer consumption.
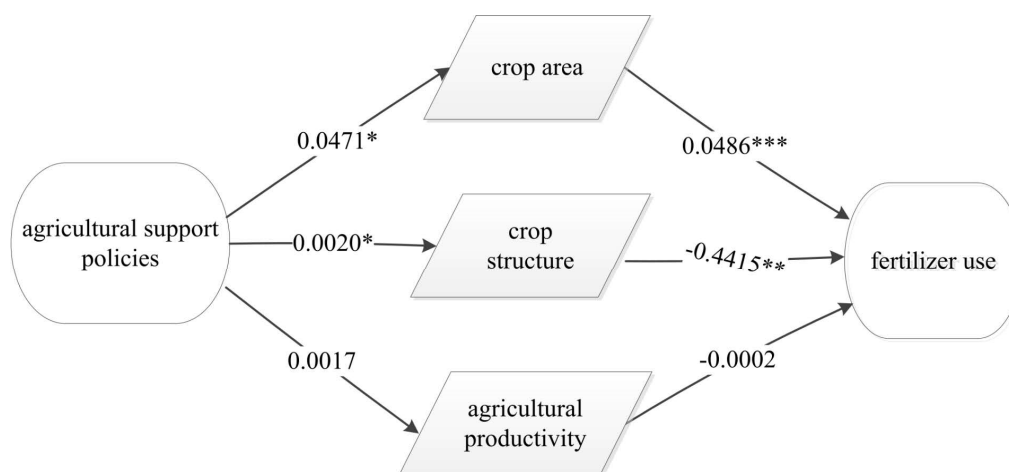
Figure 7. The Impacts of China's Agricultural Subsidies on Fertilizer Use (*, **, *** denote statistical significance levels at 10%, 5%, and 1%, respectively).

While Figure 7 included agricultural subsidies as a whole, Figure 8 illustrates the respective roles of direct and indirect subsidies in influencing crop area, crop structure, and agricultural productivity. It was obvious that indirect subsidies displayed much stronger influence, suggesting that they had greater potential to distort farmers' production decision making. In contrast, the influence of direct subsidies seemed to be minimal.
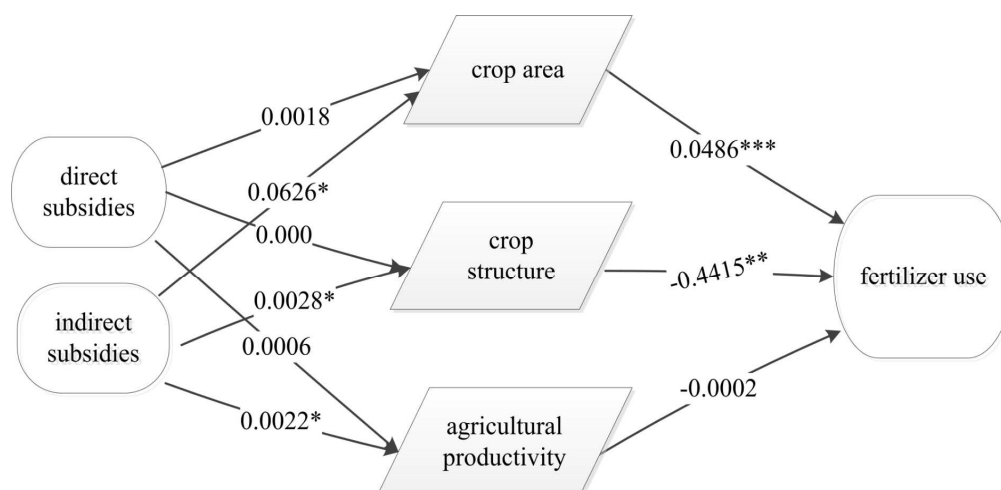
Figure 8. The Impacts of Direct and Indirect Subsidies on Fertilizer Use (*, **, *** denote statistical significance levels at 10%, 5%, and 1%, respectively).

5. Conclusions and Discussions

Using a decomposition method, this paper proposed an analytical framework to investigate the mechanisms by which ASPs affect farmers' use of fertilizers in agriculture in China. It first decomposed the influence of ASPs on farmers' production decision making into "three effects" (scale effect, structural effect, and technological effect), and then analyzed how the three effects translated into the impacts on fertilizer use. The framework turned out to be an effective tool in helping us understand the channels through which agricultural subsidies affect fertilizer use in China.

Several findings from the study are worth noting. First, China's agricultural support polices, as a whole, significantly contributed to the increased use of agricultural fertilizers through encouraging farmers to bring more land under cultivation. Meanwhile, some policies also helped offset the scale effect and reduce fertilizer consumption when farmers were motivated to increase the area of subsidizes crops (especially grains crops). As predicted, the role of technological progress in influencing fertilizer use appeared to be minimal and largely uncertain. Second, the separation of direct and indirect subsidies helped reveal the specific effects of different types of support. Both direct and indirect subsidies played a positive role in expanding crop area, adjusting crop structure, and improving agricultural productivity. But indirect subsidies appeared to be much more influential. In particular, indirect subsidies played a much greater role in increasing crop area than direct subsidies, which suggests that indirect subsidies were also a much larger contributor to the increased use of fertilizers. Thirdly, this study finds that due to the specific implementation circumstances, some direct subsidies, which were supposed to be coupled support measures in theory, have acted as decoupled measures. Consequently, the actual outcome of these subsidies is not the expected and obvious. Finally, the results of the control variables used in the models confirm the conventional wisdom regarding the path-dependent nature of farmers' production decision making and their sensitivity to agricultural product price and production cost.

The results of the study have meaningful policy implications. The research showed that ASPs helped increase crop area and improve agricultural productivity. From a policy perspective, agricultural subsidies are welcoming as their impacts are line with some of the government's key policy objectives (improving agricultural production and productivity, raising farmers' income and reducing poverty). Nonetheless, people need to consider the other side of the coin. Agricultural support policies also have undesired environmental consequences. This study demonstrated that agricultural subsidies contributed to the increased use of fertilizers during 2002–2015. The growing share of grain crops in the total sown area helped reduce fertilizer need, but that effect was not large enough to complete offset the increased demand for fertilizer driven by added cropland. In other words, China's ASPs

(at least some of them) contradict another key objective of the country's rural policies—improving environmental sustainability.

In China, indirect subsidies far outweigh direct subsidies in total agricultural support. As coupled subsidies, indirect subsidies had much greater distortionary effects on farmers' production decision making than direct subsidies, which are mostly decoupled subsidies. Indirect subsidies also had greater potential causing environmental externalities by increasing fertilizer consumption. According to the WTO Agreement on Agriculture classification of domestic agricultural support, many of China's indirect subsidies may be considered as "amber box" measures, and many are not in full conformity with WTO rules [84]. "Amber box" subsidies, or coupled subsidies, such as direct payments tied to production and price supports, tend to distort trade or production and thus are the target of WTO disciplines. "Green box" subsidies, or decoupled subsidies, are those that have minimal or no trade—or production-distorting effects. Therefore, they are not limited by WTO rules [85], [86] (p. 23). Taking those into consideration, China needs to reduce or revise coupled subsidies. Indeed, the government has realized the problems associated with some of the indirect subsidies and started to take measures to address them. It has been acknowledged that reforming coupled subsidies that are centered on product price subsidies is one of the most urgent and challenging reform areas in agricultural policy [66].

Meanwhile, China's agriculture support policies need to be geared toward more "green box" measures. Instead of using measures from the "amber box", as argued by Zhu [84], and Yu and Jensen [85], "green box" measures, should be considered with high priority. In addition to making better use of existing decoupled measures, new support measures should be designed and implemented. For example, research has found that increasing public investment in agricultural research and rural production infrastructure will improve agriculture production in a cost-effective manner [84]. This is particularly important given that technology, as shown in the study, has not played a significant role in effectively reducing fertilizer consumption at the national level. It is crucial to increase public investment in education and training programs to help farmers accept, adopt, and properly utilize agricultural technologies especially those environment-friendly technologies. The soil testing and formula fertilization technology, for example, should be further promoted and disseminated among farmers to improve fertilizer use efficiency and reduce nutrient loose as well as non-point source pollution. As Cui et al. [83] have reported, it is a great challenge to equip millions of smallholder farmers in China with new, science-based management practices; but it is also an area with great potential. As Wu and Yan [87] found, based on their study conducted in Heyang County, Shaanxi Province, that providing comprehensive technological guidance could help farmers significantly reduce the excessive application of fertilizers.

Indirect, or coupled subsidies, seem to have greater environmental impacts and are subject to WTO scrutiny. But direct, or decoupled, support measures are not without problems. In practice, some direct subsidies, including seed subsidies, direct payments to grain producers, and general agricultural input subsidy, are distributed ubiquitously based on the amount of farmland or the number of people each household has. While this situation makes these subsidies de facto decoupled, "green box" measures, it also brings about some issues. The expected role of these measures in boosting output is weakened as some farmers may not use the subsidies in the production. As many rural households are facing labor shortage in farming, the substitution of agrochemicals for labor occurs. A large and growing proportion of Chinese farmers are becoming part-time farmers [49,88]. Some hold additional jobs in nearby cities while many work in cities year around, leaving the farmland to the hands of women and the elderly. Theoretically, farmers could increase other production inputs as substitutes for labor. One of the most common substitution for labor is mechanization. However, mechanical substitution is constrained by the terrain and small farm lots. Moreover, there are relatively few agricultural machines designed for small-scale or elderly farmers. On the other hand, agrochemical substitution (i.e., fertilizers and pesticides) is less restrictive. Farmers could choose to reduce fertilization times and increase fertilization amount to ease labor constraints [89].

Thus, the government could consider reducing or eliminating some of the ubiquitous subsidies, and design new policies that help deliver subsidies to farmers that can make more efficient and more environmentally-friendly use of land. At the same time, China should continue and enhance its policies on encouraging land concentration through land use right transfer (*tudi liuzhuan*) and "appropriately scaled operations" (*shidu guimo jingying*) (CCP Central Committee and the State Council 2015). Studies have found that, in China, larger farm sizes are often associated with reduced agrochemical use, the increased use of conservation technologies as well as improved labor productivity [81,82]. In addition, as agriculture in China increasingly involves players in addition to farmers, such as specialized farmers' cooperatives and agribusinesses, new agricultural subsidy models should provide incentives to all these shareholders.

To be sure, it is unfair to put all the blame on China's ASPs for the country's high and continuously rising fertilizer consumption. Nevertheless, it deserves attention from policy makers that some agriculture support policies are not well aligned with the country's long-tern goals of agricultural and rural development. In order to effectively cope with the *sannong wenti* and achieve sustainable rural development, China needs to reconcile its agricultural and rural policies. Many policy measures and adjustments, including the policy recommendations made in this study, may be considered in order to find best policies.

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