https://doi.org/10.17221/412/2024-AGRICECON

Can agricultural subsidy reform promote reduction of fertiliser nonpoint source pollution? Evidence from China

Fusheng Liang[1], Guangsi Li[2,3], Wo-lin Zheng[4], Fangyuan Sun[1], Qian Yang[1]*

[1]Institute of Food and Strategic Reserves, Nanjing University of Finance & Economics, Nanjing, P.R. China
[2]Institute of Food and Strategic Reserves, Nanjing University of Finance & Economics, Nanjing, P.R. China
[3]Modern Grain Circulation and Security of Collaborative Innovation Center, Nanjing University of Finance & Economics, Nanjing, P.R. China
[4]School of Credit Management, Guangdong University of Finance, Guangzhou, P.R. China

**Corresponding author: guangsili@163.com*

Citation: Liang F., Li G., Zheng W.L., Sun F., Yang Q. (2025): Can agricultural subsidy reform promote reduction of fertiliser nonpoint source pollution? Evidence from China. Agric. Econ. – Czech, 71: 485–501.

Abstract: The substantial increase in grain production stimulated by traditional agricultural direct subsidies has been accompanied by a concomitant decrease in ecological quality, precipitated by excessive application of chemical fertilisers, which has generated countervailing effects that fundamentally undermine the positive effect of subsidy policies on agricultural output. Consequently, the mitigation of agricultural pollution and the elevation of ecological quality have emerged as pivotal directions for the reform of agricultural subsidies. Using both time-varying difference-in-differences (DID) models and spatial DID models in this study, we examined the effect of agricultural 'three subsidies' reform on agricultural fertiliser nonpoint source pollution (AFNSP), drawing on China's province-sector panel data from 2008 to 2022. The empirical evidence yields several salient findings. First, the three subsidies reform can significantly reduce AFNSP and improve ecological quality. Second, the large-scale operation of agricultural households and the enhancement of agricultural production efficiency serve as effective pathways for the three subsidies reform to reduce AFNSP. Third, the implementation of the three subsidies reform engenders significant spatial spillover effects, which play a crucial role in reducing overall regional AFNSP. Fourth, the efficacy of the three subsidies reform exhibits heterogeneity across diverse agroecological contexts and farming cultures. Last, the reform has resulted in notable improvements in agricultural ecological quality, thereby reinforcing food security capabilities. These findings not only offer valuable reference for refining agricultural subsidy reform but also contribute to the development of a comprehensive framework that simultaneously safeguards agroecological security and food security.

Keywords: chemical fertiliser pollution; agricultural tradition; food security; scale effect; 'three subsidies' reform

Supported by the National Social Science Fund of China (Project No. 23FJYA001), the Humanities and Social Science Fund of Ministry of Education, P.R. China (Project No. 23YJA630151), the Humanities and Social Science Fund of Ministry of Education, P.R. China (Project No. 23YJC790204).

https://doi.org/10.17221/412/2024-AGRICECON

In developing and transition economies, reducing agricultural pollution and ensuring agroecological security are vital for food production, productivity and national food security (Fan et al. 2023a). Agricultural nonpoint source pollution (ANSP) constitutes the primary component of agricultural pollution, with excessive fertiliser application and low utilisation efficiency identified as key contributors to nonpoint source pollution (Xue et al. 2020). Although chemical fertilisers have played a pivotal role in boosting crop yields since their introduction, their indiscriminate use has engendered significant ecological challenges, particularly in China with its substantial population and vast geographical area (Tang et al. 2016, Tang et al. 2019). The excessive application of chemical fertilisers has exacerbated soil and water quality degradation, leading to a critical decrease in farmland health (Hu and Liu 2024). Consequently, China has become the world's leading emitter of greenhouse gases in agriculture, and ANSP continues to worsen and stands as the predominant source of nonpoint source pollution (Chen et al. 2017). This intensification of agricultural environmental pollution adversely affects grain production and poses a significant threat to long-term food security (Yang et al. 2022).

It is imperative to promote the reduction of agricultural fertiliser overuse for agroecological security, sustainable food production and food security (Duan et al. 2021). Investigators in previous studies have demonstrated that agricultural subsidies are crucial policy instruments to support agricultural development and ensure food security (Hennessy 1998; Sun and Nie 2015; Nie et al. 2016; Chen et al. 2017; Lee et al. 2024). However, the orientation of agricultural subsidies has significantly shaped their implementation outcomes. The introduction of three direct agricultural subsidy policies in China – specifically the seed subsidy, the direct subsidy for grain farmers and the comprehensive agricultural subsidy – operating under the supply-preserving and yield-orientated paradigms, had inadvertently neglected ecological carrying capacity considerations and thereby exacerbated environmental pollution in agricultural production. Consequently, China initiated agricultural subsidy reform in 2015, commonly referred to as the 'three subsidies' reform.

The policy is orientated toward green ecology and has evolved into a de facto green agricultural subsidy. The three subsidies reform, in theory, could guide farmers to reduce the use of chemical fertilisers and enhance soil quality by precisely allocating subsidy funds. In 2015, China's consumption of chemical fertilisers stood at 60.22 million tonnes; this amount had been reduced to 50.2 million tonnes by 2023. However, the path dependence of subsidy fund distribution, the rising costs of new subsidy methods and the discrepancies in agricultural production targets between central and local governments cast doubt on the actual effectiveness of the three subsidies reform in improving agricultural environmental quality. Whether the three subsidies reform can reverse the negative environmental externalities of agricultural production, promote the reduction of agricultural fertiliser nonpoint source pollution (AFNSP) and achieve the green development of agriculture still needs further analysis.

As a common and effective policy instrument in agricultural production, researchers have conducted extensive analyses on the efficacy of agricultural subsidies. First, agricultural output growth remains the primary objective of agricultural subsidies. The grain sown area has experienced significant expansion driven by subsidy incentives (Yi et al. 2015; Fan et al. 2023b), whilst simultaneously promoting grain output growth and ensuring national food security (Walls et al. 2018). Second, the effect on farmers' income constitutes another crucial policy goal. Agricultural subsidies can enhance farmers' enthusiasm for grain cultivation and directly drive income growth (Bai et al. 2022; Sha et al. 2024). However, differential effects exist between input subsidies and output subsidies, leading to inconsistent effects on rural income disparities (Tang et al. 2024). Zhang's (2024) research further demonstrates that agricultural subsidies exert more pronounced effects on low-income groups. In addition, recent years have witnessed growing attention to the environmental effects of agricultural subsidies, with progressively deeper analyses of their effects on agricultural carbon emissions, green agricultural production and fertiliser usage (Zhang et al. 2025; Guo et al. 2021; Ke and Huang 2024). Achieving sustainable agricultural development necessitates substantive adjustments and systematic reforms in subsidy mechanisms (Laborde et al. 2021). Furthermore, issues such as farmland rental rates and land transfer have gained increasing attention in China and other developing countries experiencing gradual marketisation of land markets. The actual beneficiaries of farmland rental income significantly influence policy implementation effectiveness (Kirwan and Roberts 2016; Ciaian et al. 2021).

https://doi.org/10.17221/412/2024-AGRICECON

Researchers have predominantly focussed on the three subsidies policy reform, examining its cost-effectiveness evaluation, economic outcomes and technological effects. For instance, the cost of agricultural subsidies is a critical factor that constrains the implementation and has been one of the driving forces behind the three subsidies reform. Some researchers have analysed the significance of reducing subsidy costs and implementing precision subsidies from historical or game theory perspectives (Zhang et al. 2021). Land circulation and grain production are key economic concerns relating to agricultural subsidisation. Researchers have posited that the three subsidies reform, by altering the subsidy paradigm, has contributed to an escalation in land rental rates and the capitalisation of land (Liang et al. 2018; Zhang et al. 2020). However, the three subsidies reform can also promote the scale of land circulation (Yang et al. 2022), optimising the potential of agricultural cultivation patterns, thereby achieving a boost in grain production (Walls et al. 2018). Agricultural green technology progress has also garnered significant research attention. Empirical evidence indicates that both the total factor productivity growth rate and the pure technical efficiency of grain production have increased after the policy's implementation, suggesting that agricultural technological progress extends beyond the mere scaling of agricultural techniques (Zheng et al. 2023).

The 'green orientation' of the three subsidies reform makes its environmental effect impossible to ignore. Elucidating the environmental effect of agricultural three subsidies reform on AFNSP can facilitate the transference of the experience of agricultural subsidy reform to other developing countries. Hence, we use data from 30 Chinese provinces from 2008 to 2022 to analyse empirically the mechanisms by which the three subsidies reform influences AFNSP. Furthermore, we explore the moderating effect of rural labour mobility driven by nonagricultural opportunities and investigate the subsidy mechanisms that ensure agroecological safety and enhance the capacity for grain production.

The contributions of this research are as follows. First, the existing literature provides a relatively comprehensive analysis of the environmental effects of traditional agricultural subsidy policies, but studies on the environmental effects of targeted agricultural subsidy policies remain limited. Research on China's explicitly environmentally orientated three subsidies reform has been relatively scarce, particularly in relation to environmental pollution issues, with specific emphasis on nonpoint source pollution. This research fills the gap in the development of environmental agricultural subsidies by exploring the efficacy and pathways of the three subsidies reform on AFNSP. Second, we expand the scope of policy research by integrating the effects of the minimum wage standard's opportunity cost on rural labour migration into our analytical framework, which offers innovative perspectives for future endeavours focussed on reducing agricultural pollution and bolstering the ecological security within the agricultural sector. Third, this research incorporates the theory of spatial spillover effects, taking into account regional and agricultural cultural diversity, to deepen the understanding of the environmental effect of the three subsidies reform. This method provides a new reference for contextualised and synergistic regional development of agriculture and offers valuable insights for agricultural subsidy reform in developing countries. Fourth, we forge a robust connection between food security and agroecological security, delving into the enduring environmental implications of the three subsidies reform.

Theoretical analysis

Three subsidies reform and AFNSP. Farmers adhere to the utility maximisation principle in factor allocation during agricultural production decision-making. The three agricultural subsidies implemented since 2003 – the crop variety improvement subsidy, direct grain planting subsidy and comprehensive agricultural inputs subsidy – exerted incentive effects on farmers' grain production decisions. Farmers adopted a resource allocation pattern prioritising increased chemical inputs to achieve rapid growth in grain yields. However, issues such as diminishing marginal utility of inputs and deterioration in cultivated land quality caused by excessive fertiliser use undermined the sustained effectiveness of subsidy policies and agricultural sustainability. To advance grain yield growth and sustainable agricultural development simultaneously, China initiated agricultural subsidy reforms by consolidating the three subsidies into the agricultural support and protection subsidy policy.

The three subsidies reform in China is orientated toward green development, aiming to achieve sustainable agricultural development by enhancing soil fertility conservation and promoting moderate-scale farming to boost grain production. This green-orientated approach in agricultural subsidy reform aligns

https://doi.org/10.17221/412/2024-AGRICECON

with trends observed in the European Union (EU) and U.S. agricultural subsidy systems. The EU's Common Agricultural Policy (CAP) reform has shifted from production subsidies to green payments, driving reductions in pollution per unit of agricultural production (Gocht et al. 2017; Coderoni and Esposti 2018), whereas the United States has increased support for agri-environmental subsidies – particularly through the Environmental Quality Incentives Program (EQIP) – which has significantly improved local water quality (Liu et al. 2023). China's three subsidies reform now imposes requirements on cultivated land fertility and soil quality, explicitly stating that 'subsidies will no longer be granted to land failing to meet cultivation quality standards' (Zhu et al. 2024), thereby emphasising the conservation of agroecological systems. Under the dual incentives of securing subsidies and improving farmland quality, which directly affects grain yields, the reform stimulates farmers' enthusiasm for adopting practices such as fallowing, straw return to fields, deep loosening and land preparation, by reducing chemical fertiliser and pesticide use, fostering a balanced approach to land use and conservation (Repetto 1987).

In the specific distribution process of agricultural subsidy funds, the three subsidies reform uses targeted subsidies and enhanced oversight of fund flows to regulate and guide farmers' resource allocation behaviour in agricultural production. This process drives farmers to increase the proportion of organic fertiliser purchases and reduce chemical fertiliser use, thereby preserving soil fertility and boosting grain yields. Concurrently, support for moderate-scale farming operations accelerates agricultural production mechanisation, promotes large-scale technological adoption, expands agricultural social services and enhances the efficient use of agricultural resources, thereby mitigating nonpoint source pollution from chemical fertilisers (Kansanga et al. 2019; Guo et al. 2021).

Thus, with the consolidation of the three subsidies into the Agricultural Support and Protection Subsidy Policy, farmers in agricultural production will reduce their reliance on chemical fertilisers and optimise chemical inputs, leading to a gradual decrease in fertiliser use. The three subsidies reform contributes to reducing nonpoint source pollution from fertilisers, ameliorating the negative environmental externalities of agricultural production and enhancing agricultural ecological quality. On the basis of this analysis, we propose H_1.

H_1: The agricultural three subsidies reform can reduce AFNSP and thereby improve agroecological quality.

Three subsidies reform, large-scale operations and AFNSP. As an important dimension of the environmental effect on economic growth (Selinger 1993), scale effects have also been highlighted in agricultural subsidy reform. Subsidies for moderate-scale food operations based on land management rights have accelerated land transfers, particularly the influx of large-scale farmers (Yang et al. 2022), and shifts in agricultural production patterns and production scales have also helped to reduce reliance on chemical fertilisers (Fan et al. 2023a).

Large-scale farming operations, including those of the family farm and large grain farming varieties, as well as other new agricultural operating entities, have emerged as a viable avenue for reforming the three subsidies policy to reduce AFNSP (Duan et al. 2021). On the one hand, the three subsidies reform has had the effect of strengthening the support for actual grain farmers as the mainstay. The higher the scale of operation, the higher the standard of cash subsidies (Ren et al. 2019), and the proportion of large-scale farmers continues to grow. Compared with smallholders, who are more likely to use more polluting fertilisers and pesticides because of financial constraints, large-scale farmers demonstrate a more optimal factor allocation pattern, which enables the specialisation of agricultural production and economies of scale, as well as a more efficient specialisation of fertiliser use and fertiliser category selection (Zhan and Hu 2017). Concurrently, the increasing scale improves precision fertilisation capability and reduces fertiliser demand (Guo et al. 2022). On the other hand, the three subsidies reform has accelerated the transformation of agricultural production methods of large-scale farming operations and the improvement of agricultural production efficiency. The increase in production efficiency at scale has concomitantly reduced the use of chemical fertiliser.

Consequently, new agricultural operating entities demonstrate a reduced reliance on traditional fertilisers and exhibit a higher utilisation rate. The three subsidies reform will facilitate the growth of the scale and proportion of new agricultural operating entities, which will effectively promote a reduction in the application of chemical fertilisers and facilitate the reduction of agricultural chemical fertiliser surface sources. In this study, we put forth a second hypothesis.

H_2: The three subsidies reform reduces AFNSP by promoting an increase in the proportion of large-scale operations.

https://doi.org/10.17221/412/2024-AGRICECON

Three subsidies reform, agricultural production efficiency and AFNSP. Production efficiency holds significant importance in the agricultural sector (Adom and Adams 2020) and plays a pivotal role in advancing sustainable agricultural development (Pourzand and Bakhshoodeh 2014). Enhancing agricultural production efficiency serves as a critical strategy for reducing nonpoint source pollution caused by fertiliser use. The three subsidies reform, by promoting shifts in production models and influencing the adoption of agricultural technologies, drives changes in agricultural production efficiency (Liu et al. 2019b), thereby further exerting effects on fertiliser-induced nonpoint source pollution.

Firstly, the three subsidies reform promotes the adoption of agricultural machinery and innovative technologies. Agricultural machinery has a higher efficiency and lower loss in fertiliser application than does manual labour (Duan et al. 2021), enabling precision fertilisation and reducing fertiliser use. Innovations in deep tillage and sub-surface fertilisation machinery contribute to improved soil fertility, enhanced nutrient utilisation efficiency and increased agricultural production efficiency, ultimately reducing fertiliser demand (Baumhardt et al. 2008). Secondly, the agricultural sector exhibits a growing trend toward specialised and industrialised services (Cao et al. 2024), which further elevates production efficiency. During the smallholder-dominated era, agricultural subsidies struggled to facilitate the penetration of agricultural technical services into rural areas. However, green ecology-orientated subsidies not only stimulate the growth of new agricultural entities but also alleviate farmers' financing constraints and encourage the adoption of technical services (Li et al. 2023; Xu et al. 2024). As large-scale farmers adopt these services, economies of scale lower the cost of technical services, fostering technology spillover and signalling effects that drive technology adoption among neighbouring smallholders (Meng et al. 2024). This process has enhanced agricultural production efficiency and improved fertiliser input efficiency.

Overall, the three subsidies reform promotes the application of new technological innovations in agricultural production and improves production patterns, thereby enhancing agricultural production efficiency, which in turn increases fertiliser resource use and reduces nonpoint source fertiliser pollution. On the basis of this analysis, we propose hypothesis 3.

H_3: The three subsidies reform reduces AFNSP by promoting agricultural production efficiency.

Three subsidies reform, minimum wage standard and AFNSP. The rapid development of the agricultural economy has resulted in notable changes within the factor market, with prices of labour and capital factors experiencing a gradual convergence with those observed in other industries. The three subsidies reform has not had a significant effect on improving the price distortion of the labour force itself, and low returns associated with traditional agriculture have prompted the labour force to re-evaluate their employment decisions. As a system for regulating income distribution in the labour market and labour mobility between urban and rural areas (Yang and Gunderson 2020), a higher minimum wage standard has led to an increase in nonagricultural incomes (Liu et al. 2023), which has accelerated the outflow of rural labour.

Concurrently, the three subsidies reform in agriculture has clarified that the intended beneficiaries of the subsidies are the actual operators. Consequently, the shift in the subsidy recipients has redirected the subsidy funds to land rent (Ren et al. 2019), resulting in an increase in land rents. The theory of opportunity cost of production suggests that the existing cost-benefit constraints of lower food prices and higher agricultural production costs and the opportunity cost constraints on nonfarm earnings from a higher minimum wage make the transfer of land management rights more favourable (Liu et al. 2019a). This process will accelerate the mobility of agricultural labour, pushing the proportion of large-scale farmers and the proportion of nonfarmers to increase in a clear trend (Bhorat et al. 2014), and increase the efficiency of fertiliser use. In addition, the mobility of labour forces the use of technology-intensive factors of production, promoting the progress of agricultural technology and realising the excessive growth of agriculture from the 'exploitative' growth of labour to the 'technological' growth, thus reducing the input of factors of production such as fertiliser (Zhou et al. 2024). The increase in the minimum wage standard and accelerated labour mobility, coupled with accelerated farmland transfer under agricultural subsidies, the growth in large-scale farming operations and advancements in agricultural technology, collectively contribute to reducing fertiliser use. Thus, we propose hypothesis 4.

H_4: The higher minimum wage standard accelerates labour mobility, which in turn helps to enhance the effectiveness of the three subsidies reform.

MATERIAL AND METHODS

The three subsidies reform was initially implemented on a pilot basis in 2015 and subsequently

https://doi.org/10.17221/412/2024-AGRICECON

fully implemented in 2016. Since the implementation of the three subsidies reform, the quality of agroecology has continued to improve. When the three subsidies reform was implemented, there were differences in subsidy standards across regions, especially in the requirements for farmland protection (Liu and Xu 2023), which provided conditions for assessing the effect of policy at the provincial level. Therefore, we treated the 'three subsidies' reform as a quasi-natural experiment. In this study, we used a time-varying difference-in-differences (DID) model to test the effect of the three subsidies reform on AFNSP. The baseline model is as follows:

$$Y_{it} = \beta_0 + \beta_1 Treat_i \times Post_t + \beta_2 X_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (1)$$

where: Y_{it} – the explanatory variable of this study, which adopts AFNSP to evaluate the efficacy of policy implementations on agricultural pollution and agroecological governance; i and t – province and time, respectively; X_{it} – the control variable in this study; β_1, β_2, β_3 – estimated coefficients; μ_i – the province fixed effect; ν_t – the time-mixed effect; ε_{it} – a random disturbance term.

In this study, we used a two-step approach to test the mediating effect. Drawing on the study of Chen et al. (2020), we constructed the following mechanism model.

$$M_{it} = \beta_0 + \beta_1 Treat_i \times Post_t + \beta_2 X_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (2)$$

where: M_{it} – the mediating variable; $Treat_i \times Post_t$ – the interaction term between policy dummy variables and time dummy variables; β_1 – model coefficient.

If β_1 is significant, it indicates that there is a mediating effect.

We also introduced an interaction term to construct a moderating effect model.

$$Y_{it} = \beta_0 + \beta_1 Treat_i \times Post_t + \beta_2 Treat_i \times \times Post_t \times N_{it} + \beta_3 X_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (3)$$

where: N_{it} – the moderating variable.

If the coefficient β_2 is significant, it indicates that moderation effects exist.

We defined the variables as follows:

Explained variable. We used AFNSP as an explanatory variable. The nutrient-based agricultural surface source pollution caused by excessive application of chemical fertilisers is an important indicator of agroecological quality (You et al. 2024). Using an inventory analysis method, we identified AFNSP as nitrogen fertiliser, phosphorus fertiliser and compound fertiliser (Niu et al. 2022), and the calculation formula was as follows:

$$Pollution = \sum PE_i \times \rho_i \times \eta_i \quad (4)$$

where: *pollution*– the total amount of AFNSP; PE_i – the number of pollution statistical indicators of the pollution unit *i;* η_i – the fertiliser loss rate of the pollution unit; ρ_i – the pollution production coefficient.

Referring to the study of Hou and Yao (2019), we set the total nitrogen production coefficients of nitrogen fertilisers, phosphorus fertilisers and compound fertilisers to be 1, 0 and 0.33, and we set the total phosphorus production coefficients to be 0, 0.44 and 0.15, respectively.

Core explanatory variables. The core explanatory variable $Treat_i \times Post_t$ of this study is the interaction term between policy dummy variables and time dummy variables – namely, the three subsidies reform policy. Taking into account the differences in food production status and subsidy standard requirements of each province, $Treat_i$ selects the main grain-producing provinces as the treatment group to measure the effect of policy implementation. $Post_t$ represents the policy point in time variable, which is 1 after the implementation of the policy and 0 before the implementation of the policy. As Henan province was not included in the pilot provinces in 2015, but three subsidies reform in Henan had already started in the province, we calculated the time of the policy in Henan on the basis of the actual implementation time.

Mechanism analysis variables. On the basis of previous analyses, we selected the scale of land inflow (*Scale*), agricultural production efficiency (*APE*) and minimum wage (*Wage*) to refer to the mechanism analysis variables. We calculated the land inflow scale by using the ratio of the area transferred into family farms and above-scale subjects to the area under a family joint contract. We used this ratio to measure the scale of operations. We used the Super-SBM model to evaluate agricultural production efficiency, incorporating pollution-related undesirable outputs into the analysis. We used the minimum wage standard to assess rural labour mobility from the vantage point of opportunity cost, nonfarm in-

https://doi.org/10.17221/412/2024-AGRICECON

come attractiveness and other pertinent factors. This minimum wage standard is based on the wage standards issued by provinces over the past several years, which set values above the median minimum wage in the year of policy implementation (2016) as 1 and otherwise as 0.

Control variables.

i) Urbanisation level (*City*): the ratio of urban population to the yearend resident population of the region.

ii) Road density (*Road*): the ratio of the length of village roads in the administrative district and the administrative area of the district.

iii) Agricultural industrial structure (*Agrind*): the ratio of the sown area of food crops to the sown area of agricultural crops.

iv) Industrialisation level (*Secind*): the ratio of value added of secondary industry and regional GDP.

v) Income gap (*Ingap*): the ratio of disposable income of urban residents to that of rural residents.

vi) Agricultural irrigation level (*Agrinf*): the ratio of effective irrigated area and sown area of crops.

vii) Disaster-affected area (*Harm*): the annual area affected by agricultural natural disasters in each province.

viii) Rainfall (*Rain*): average annual rainfall in each province.

ix) Education level (*Edu*): the percentage of people aged 6 years and older who had received college education or more.

x) Agricultural mechanisation (*Machine*): the total power of agricultural machinery in each province.

xi) Environmental regulation (*ER*): the proportion of completed investment in industrial pollution control in the secondary industry.

We sourced the data from the China Statistical Yearbook 2009–2023, China Rural Statistical Yearbook 2009–2023, China Industrial Statistical Yearbook 2009–2023, China Rural Economic Management Statistical Annual Report 2008–2023, National Bureau of Statistics database and the Economy Prediction System (EPS) database. We supplemented some missing values by interpolation and moving average methods. Descriptive statistics for each variable are presented in Table 1.

RESULTS AND DISCUSSION

Benchmark regression

Table 2 reports the regression results of the baseline model, which examines the effect of the implementation of the three subsidies reform on local AFNSP. The estimation results presented in columns one and two illustrate the effect of including or excluding control variables. The coefficients of the core explanatory variables underwent a notable reduction in absolute value when control variables were incorporated, suggesting that the estimation results are more robust when control variables are taken into account. The coefficients of the core explanatory variables were negative at the 1% significance level, irrespective of whether controL variables were included. The implementation of the three subsidies reform had a significant effect on the management of AFNSP. Its implementation effectively reduced fertiliser application and fertiliser pollution and played a role in ensuring agroecological security by leveraging the fertiliser reduction effect of the policy implementation, which helped prove our H_1.

Parallel trend tests

Examination of the average treatment effect of the implementation of the three subsidies reform requires the model to adhere to the parallel trends assumption for the control and experimental groups before the implementation of the policy (Marcus and Sant'Anna

Table 1. Descriptive statistics

Variables	*n*	Mean	SD	Min.	Median	Max.
Pollution	450	16.34	12.12	0.45	16.71	58.64
Treat × Post	450	0.21	0.41	0	0	1
Scale	450	0.15	0.15	0	0.11	1.11
APE	450	1.11	0.15	0.71	1.06	2.21
Wage	450	0.50	0.50	0	0.5	1
City	450	0.58	0.13	0.29	0.57	0.9
Road	450	0.44	0.31	0.01	0.4	1.76
Agrind	450	0.66	0.14	0.36	0.67	0.97
Secind	450	0.42	0.08	0.16	0.42	0.62
Ingap	450	2.62	0.42	1.83	2.56	3.95
Agrinf	450	0.44	0.18	0.17	0.38	1.23
Harm	450	0.17	0.13	0	0.13	0.7
Rain	450	2.89	1.46	0.56	2.6	6.34
Edu	450	0.14	0.08	0.03	0.12	0.5
Machine	450	0.64	0.24	0.24	0.58	1.39
ER	450	8.07	6.08	2.56	6.11	36.05

Agrind – agricultural industrial structure; *Agrinf* – agricultural irrigation level; *APE* – agricultural production efficiency; *City* – urbanisation level; *Edu* – education level; *ER* – environmental regulation; *Harm* – disaster-affected area; *Ingap* – income gap; *Machine* – agricultural mechanisation; *Rain* – rainfall; *Road* – road density; *Scale* – scale of land inflow; *Secind* – industrialisation level; *Wage* – minimum wage
Source: Author's compilation

https://doi.org/10.17221/412/2024-AGRICECON

Table 2. Benchmark regression results

Variables	(1)	(2)
	Pollution	*Pollution*
Treat × *Post*	−2.217***	−1.492***
	(0.780)	(0.450)
Controls	no	yes
Cons	16.807***	44.102***
	(0.160)	(8.770)
Province	yes	yes
Year	yes	yes
n	450	450
Adj. R^2	0.985	0.989

***significance level at 0.01
Source: Author's compilation

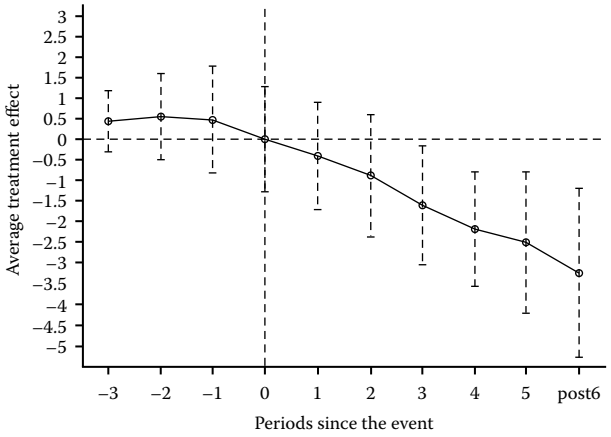

Figure 1. Parallel trend test

Source: Author's compilation

2021); therefore, we constructed the following dynamic analytical equation:

$$Y_{it} = \beta_0 + \beta_1 \sum_{k=-3,\, k\neq -1}^{6} \mu_k \times \text{Treat}_i \times \text{Post}_t + \beta_2 X_{it} + \mu_i + \nu_t \quad (5)$$

We used the actual year of implementation of the three subsidies reform as the base period. Given the specificities of policy formulation and implementation in China, we excluded data from the year before policy implementation. The results are shown in Figure 1. Before the implementation of the policy, the coefficient β_1 was not significantly negative. After the implementation of the policy, β_1 showed a decreasing trend and became significantly negative in the third year. The results showed that the effect of the three subsidies reform in reducing agricultural surface pollution had a certain lag. Possible reasons for the phenomenon may be the seasonality of agricultural production, the lag in publicising rural policies at the grass-roots level and the time needed for land restoration.

Robust test

Placebo test. For a better evaluation of the influence of the three subsidies reform on AFNSP, we adopted the methodology proposed by Yang et al. (2021) and used a counterfactual test. In this study, we constructed the three years before and three years after the implementation of the three subsidies reform as the counterfactual period, and the results are shown in Table 3. The regression results showed that none of the dummy time variables were statistically significantly negative, and the results were robust.

Furthermore, we conducted a placebo test by using a random selection of provinces and 1 000 random samples. The estimated coefficients of the kernel density plots and histograms of the randomised sample results are presented in Figure 2, which depicts the pertinent results. We presented the distribution of estimated coefficients mainly in proximity to the 0 value, thus eliminating the interference of other factors, and the benchmark model results were robust.

Excluding other policy effects. The three subsidies reform was initially implemented in 2015 and subsequently fully operationalised in 2016. Notable policies in the agricultural sector that had the potential to affect agroecological security included the construction

Table 3. Baseline model placebo test

Variables	(1)	(2)
	Pollution	Pollution
Treat × Pre_3	−0.292	–
	(0.250)	
Treat × $Post_3$	–	−0.327
		(0.280)
Controls	yes	yes
Cons	54.801***	54.635***
	(5.040)	(5.070)
Province	yes	yes
Year	yes	yes
n	450	450
Adj. R^2	0.989	0.989

***significance level at 0.01; *Treat* × Pre_3 – interaction term constructed between the policy and the dummy policy time
Source: Author's compilation

https://doi.org/10.17221/412/2024-AGRICECON

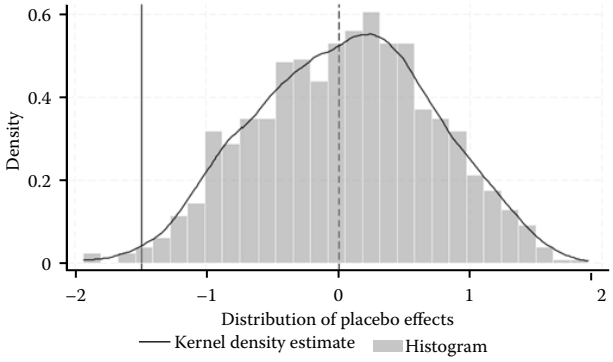

Figure 2. Placebo test

Source: Author's compilation

of high-standard farmland ('Farmland') and the introduction of the new development concept ('Concept'). To isolate the influence of these policies, we incorporated additional policy dummy variables into the benchmark model. The findings are presented in columns one through four of Table 4. After the introduction of the policy effects of Farmland and Concept, the results exhibited a notable negative trend, irrespective of the inclusion or exclusion of control variables. The results remained consistent when we considered other contemporaneous event effects.

Alternative measurements of agricultural pollution. To explore the effect of the three subsidies reform on agroecological security further, we measured agroecological quality by replacing AFNSP with agricultural carbon emissions to ensure that the conclusions were reliable. The results are shown in column five of Table 4, and the coefficient of *Treat* × *Post* was negative at the 1% significance level, indicating that the implementation of the policy could significantly reduce agricultural carbon emissions and ensure agroecological security. This finding further corroborates the conclusion of this study.

Propensity score matching-DID. To ensure comparability of the treatment and control groups, we used Cassell et al. (2013) method to match the treatment and control groups for cross-sectional propensity score matching (PSM). We set the control variables in the baseline model as covariates and used the 1 : 1 nearest neighbour matching approach. The results are shown in column six of Table 4. After PSM matching, the coefficient of *Treat* × *Post* was significantly negative, which is consistent with the baseline results. This finding further confirms the environmental effect of the three subsidies reform on reducing AFNSP.

Heterogeneity treatment effect. We considered that the timing of policy implementation varied across provinces in the study, and the traditional two-way fixed effects model may be biased due to heterogeneity. Drawing on Karplus and Wu (2023), we used the Bacon decomposition and the method proposed by Callaway and Sant'Anna for identifying heteroge-

Table 4. Eliminating policy interference, changing variables, and conducting PSM-DID robustness tests

Variables	Farmland		Concept		Alternative	PSM-DID
	(1)	(2)	(3)	(4)	(5)	(6)
Treat × *Post*	−2.187***	−1.488***	−2.193***	−1.448***	−16.476***	−2.106**
	(0.760)	(0.440)	(0.790)	(0.460)	(4.810)	(0.920)
Treat × $Post_1$	0.239	0.037	–	–	–	–
	(0.170)	(0.190)				
Treat × $Post_2$	–	–	0.504	0.802*	–	–
			(0.440)	(0.410)		
Controls	no	yes	no	yes	yes	yes
Cons	16.794***	44.085***	16.787***	44.501***	603.651***	21.670
	(0.160)	(8.760)	(0.170)	(8.650)	(107.940)	(23.700)
Province	yes	yes	yes	yes	yes	yes
Year	yes	yes	yes	yes	yes	yes
n	450	450	450	450	450	133
Adj. R^2	0.985	0.989	0.985	0.989	0.987	0.988

** and ***significance levels at 0.05 and 0.01, respectively; PSM-DID – propensity score matching difference-in-differences model

Source: Author's compilation

https://doi.org/10.17221/412/2024-AGRICECON

Table 5. Heterogeneity processing effect

Panel A Robust estimator		
	(1)	(2)
	Bacon decomposition	CSDID
Treat × *Post*	−2.217***	−2.361***
n	450	450
Panel B Weighted DID coefficients for different groups		
Group	Estimator	Weight
Early vs Late	−1.255**	1.957%
Late vs Early	0.649**	1.956%
Never vs Treat	−2.295	96.087%

** and ***significance levels at 0.05 and 0.01, respectively; CSDID – Callaway and Sant'Anna method for difference-in-difference model; DID – difference-in-differences model
Source: Author's compilation

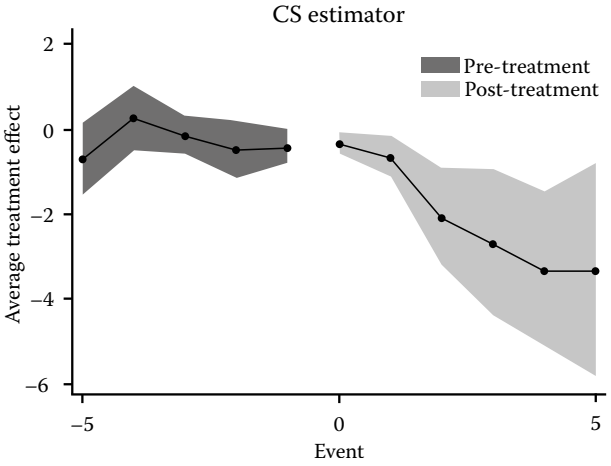

Figure 3. Alternative estimation method test: interpolation method test

CS – Callaway and Sant'Anna method
Source: Author's compilation

neous time-varying DID, namely CSDID (Callaway and Sant'Anna 2021), for decomposition purposes. The results are shown in Table 5 and Figure 3. The results of the multitemporal DID and different groups' decompositions are reported separately in Panel A, and these were significantly negative. The results of the decomposition of different groups are further reported in Panel B. The proportion of the effect of the results of the never-treated group and the treated group was as high as 96.087%, a group that generally does not exhibit heterogeneity in the treatment effect. Furthermore, the results in Figure 3 indicated that the results of the interpolation method were still significant and were generally consistent with the results of the benchmark model in this study. The results of this study are robust.

Heterogeneity test

Physical geography. China is a vast country with notable disparities in resource endowments and economic development across its diverse regions. These disparities give rise to notable differences in agricultural cultivation methods, varieties of agricultural products and agricultural technologies across the country, which has implications for agricultural policy implementation and environmental quality improvement. Thus, we have divided China into three distinct regions, delineated by their respective natural conditions and economic development factors, and the results are shown in columns one through three of Table 6.

There were significant differences in the effects of the three subsidies reform in the eastern, central and western regions. The three subsidies reform has been a catalyst for the swifter turnover of land and the vigilant safeguarding of cultivable land, resulting in a more pronounced reduction in pollution. As a major grain-producing area, the central region has faced delays in policy implementation and struggled with promoting agricultural technology services, consequently limiting progress in reducing chemical fertiliser use and improving agricultural ecology. Conversely, the western region, characterised by a scarcity of traditional farming areas and a lower reliance on chemical fertilisers owing to the types of crops cultivated, has reaped the benefits of positive policy incentives.

Cultivation history and culture. First of all, China has a long history of farming, with the two river basin tributaries of the Yangtze River and the Yellow River forming the origin of the country's farming culture and the key agricultural region (Nie et al. 2024). In this study, we chose the provinces within the Yangtze River main stream basin and the Yellow River basin ('two river basins') as the grouping variables, with the findings presented in columns four through seven of Table 6. The two river basins have a long history of agriculture, superior natural geography, accelerated land transfer after the implementation of the policy, faster adoption of new agricultural technologies such as drones and strong agroecological security.

Second, we considered the policy implementation's effect under the influence of farming culture, especially rice culture. The essence of rice culture, as postulated

https://doi.org/10.17221/412/2024-AGRICECON

Table 6. Geographic and cultural heterogeneity

Variables	East	Central	West	Two river basins	Non-two river basins	Yangtze River basin	Yellow River basin	Rice culture zone	Non-rice culture zone
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treat × *Post*	−1.659***	−1.258	−2.249**	−1.327**	−1.561	−0.674	−1.286**	−0.951	−1.457**
	(0.400)	(0.890)	(0.860)	(0.480)	(0.930)	(0.480)	(0.400)	(0.660)	(0.620)
Controls	yes	yes	yes	yes	yes	yes	yes	yes	yes
Cons	47.079***	61.097***	53.489*	40.446***	39.296***	41.498***	29.771	49.555***	49.765***
	(11.940)	(14.280)	(24.240)	(12.500)	(10.230)	(11.250)	(25.390)	(15.850)	(9.500)
Province	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year	yes	yes	yes	yes	yes	yes	yes	yes	yes
n	165	120	165	255	195	150	135	195	255
Adj. R^2	0.995	0.992	0.975	0.992	0.979	0.990	0.995	0.992	0.990

** and ***significance levels at 0.05 and 0.01, respectively
Source: Author's compilation

by the rice theory, is the spirit of collectivism that has developed over a long period of rice cultivation in East Asia (Talhelm et al. 2014). We drew on Liu and Wang (2024) to classify rice culture zones and non-rice culture zones on the basis of China's historical distribution of farming and the percentage of contemporary grain sown area devoted to rice. The rice theory suggests that the spirit of collectivism contributes to policy implementation. However, our study results indicate that the implementation effects of the rice culture zone were not satisfactory. The possible reasons for this phenomenon are the continuation of the previous form of subsidy disbursement in some areas, as well as the high bargaining price of land lease rights brought about by local protectionism under the spirit of rural collectivism in rice crop areas, which is not conducive to the efficient transfer of agricultural land to large-scale farmers. This situation ultimately led to the unsatisfactory implementation of the policy.

Mechanism discussion

Large-scale operation. The analysis presented revealed that the reform of the three subsidies policy has markedly reduced the levels of AFNSP, concurrently boosting ecological quality. What drove this positive transformation? Firstly, the primary focus was on the primary recipients of agricultural subsidies – new agricultural operating entities. In the context of China's ongoing agricultural transformation, the traditional smallholder as a production unit is no longer aligned with the green, low-carbon and sustainable development model of agriculture. Large-scale farming operations have become the focus of policy support for the transformation.

The three subsidies reform has promoted the centralised transfer of scattered and abandoned farmland to actual farming households. Concurrently, agricultural subsidies incentivise new management subjects to scale up agricultural production through transferring and contracting, accelerating the scale and specialisation of agricultural production. The scale of agricultural production firstly reduces the transaction and learning costs of farmers' production material purchases, realises the optimal combination of factor resources and alleviates the factor mismatch problem in agricultural production. In addition, large-scale operations facilitate the implementation of novel knowledge and technology in agricultural production, facilitate structural adjustments in agricultural production and enable the optimal use of fertilisers and other resources, including precision fertilisation, all of which contributes to the reduction of AFNSP and the enhancement of agroecological quality. The coefficient of *Treat* × *Post* in column one of Table 7 was significantly positive, indicating that the three subsidies reform has significantly driven the growth of the proportion of large-scale farmers, which in turn has facilitated a reduction in AFNSP. These findings helped us prove H_2.

Agricultural production efficiency. The enhancement of production efficiency demonstrates significant effects on pollution and carbon reduction. Therefore, we examined the role of agricultural production efficiency within the effect of the three sub-

https://doi.org/10.17221/412/2024-AGRICECON

Table 7. Analysis of impact mechanism

Variables	*Scale*	*APE*	*Pollution*
	(1)	(2)	(3)
Treat × *Post*	0.037***	0.062**	–0.952***
	(0.010)	(0.030)	(0.310)
Treat × *Post* × *Wage*	–	–	–1.215***
			(0.400)
Controls	yes	yes	yes
Cons	–0.220	1.292***	43.738***
	(0.330)	(0.430)	(8.480)
Province	yes	yes	yes
Year	yes	yes	yes
n	450	450	450
Adj. R^2	0.818	0.351	0.990

** and ***significance levels at 0.05 and 0.01, respectively; APE – agricultural production efficiency

Source: Author's compilation

sidies reform mechanism. The three subsidies reform emphasises cultivated land fertility protection, advocating practices such as deep tillage and straw return, which incentivise farmers to prioritise agricultural machinery and adopt new technologies, thereby driving the widespread application of mechanisation in agricultural production. Moreover, the accelerated promotion of scale operations not only facilitates the extensive adoption of technical services among large-scale farmers but also generates green technology spillover effects benefitting smallholder production. In addition, the proliferation of agricultural mechanisation and modern equipment fosters advancements in green production technologies, elevating overall production efficiency. Improved agricultural productivity efficiency serves as an effective engine for pollution reduction, enabling pollution control, cultivated land conservation and the mitigation of nonpoint source pollution from chemical fertilisers. As shown in column two of Table 7, the significantly positive coefficient of *Treat* × *Post* indicates that the three subsidies reform has substantially promoted agricultural production efficiency and contributed to the reduction of AFNSP. Our H_3 was empirically verified here.

Minimum wage. Driven by the opportunity cost of higher minimum wage standards, agricultural labour mobility, farmland size and agricultural production efficiency are affected, and agricultural production decisions are then changed, which also affects the implementation of the three subsidies. In our study, we introduced the interaction term *Treat* × *Post* × *Wage* between the minimum wage standard and the policy effect, and the results are shown in column three of Table 7. The status quo of the coefficient of *Treat* × *Post* × *Wage* was negative, and the coefficient of *Treat* × *Post* remained significant. This finding suggests that the higher minimum wage has attracted agricultural operators, accelerated off-farm employment for smallholders and driven rural labour outflows. This situation has led to the acceleration of large-scale, specialised and technologically advanced production and the reduction of AFNSP. Thus, the higher minimum wage standard accelerated rural labour mobility, which in turn reinforced the environmental improvement effect of the three subsidies reform in reducing AFNSP. Our results proved that H_4 can be significantly held.

Further discussion

Spatial spillover effect of policy. The externality of policy implementation and the spatial spillover of environmental pollution make the spatial correlations difficult to ignore, and the estimation results of the traditional ordinary least squares model may be biased. Therefore, we used a spatial DID model to test the effect of the three subsidies reform on the overall agroecology of the region, and we constructed the following model:

$$Y_{it} = \rho\sum_{j=1}^{n} W_{ij} \times Y_{it} + \beta_0 \sum_{j=1}^{n} W_{ij} \times Treat_i \times Post_t + \\ + \beta_1 Treat_i \times Post_t + \beta_2 X_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (6)$$

where: W_{ij} – the spatial weight matrix.

We used the neighbouring spatial weight matrix in this study. Considering the errors in the estimated coefficients, we chose to present the results of the spatial effects decomposition as shown in columns one through three of Table 8. The three subsidies reform will not only catalyse a decrease in AFNSP within our province but also, through a cascade of positive effects – such as technology diffusion, cross-regional integrated operations, mobility of agricultural technical services and the transmission of soil fertility – will inspire reduction in AFNSP in neighbouring provinces, all of which will culminate in a comprehensive enhancement of the regional agricultural ecosystem.

Grain production safety. Securing the capability for food production is the core goal of the three subsidies reform initiative, and the fundamental objective of mitigating AFNSP and enhancing agroecological

https://doi.org/10.17221/412/2024-AGRICECON

quality is similarly to ensure food security. Therefore, we included the quantity of food output as an explanatory variable in the analysis. Considering the lagged effects of reducing fertiliser application and protecting arable land, we also set up the following equation, drawing on the study of Li and Zhou (2023), to explore the short-term and long-term effects of the three subsidies to safeguard agroecology and food production:

$$Y_{it} = \beta_0 + \beta_1^s Treat_i \times Post_t^s + \beta_2^L Treat_i \times \\ \times Post_t^L + \beta_3 X_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (7)$$

where: β_1^s and β_2^L – the short-term and long-term causal effects of policy implementation, respectively.

Columns four and five of Table 8 present the overall effects and short- and long-term effects, respectively. The estimated coefficient of column four is significantly positive, indicating that the three subsidies reform had a beneficial effect on agricultural ecology and was able to promote food production growth effectively. The estimated coefficients of β_1^s and β_2^L in column five were both significantly positive, with the value of β_2^L being even higher. This finding indicates that improvements in ecological governance contributed to increased food production. The evidence demonstrates that the reduction of AFNSP and the amelioration of ecological conditions within the agricultural sector, as a result of policy enforcement, can substantially promote the productivity of grain crops and ensure the stability of food supplies.

CONCLUSION

In recent years, environmental issues in agriculture have gradually been a subject of focus, and agricultural subsidy, which has played an important role in agricultural production, has gradually attracted attention. However, there have been limited studies on the environmental effects of China's green-orientated three subsidies reform. Therefore, in this study, we analysed the effects of the three subsidies reform from the perspective of agroecological security. Using a panel of 30 provinces in China from 2008 to 2022, we considered the three subsidies reform as a quasi-natural experiment and examined its effects on reducing AFNSP and improving ecological quality.

With the use of time-varying DID estimation, we were able to present several useful findings from this study. First, the implementation of the three subsidies reform has effectively promoted the reduction of AFNSP, which has contributed to ensuring agroecological security. Second, the three subsidies have reduced AFNSP by promoting large-scale agricultural operations and accelerating agricultural production

Table 8. Spatial DID and grain output

Variables	Direct	Indirect	Total	Gain yield	Grain yield
	(1)	(2)	(3)	(4)	(5)
$Treat \times Post$	−1.249***	−1.936***	−3.190***	474.533***	–
	(0.270)	(0.570)	(0.600)	(104.200)	
$Treat \times Post_t^s$	–	–	–	–	219.196***
					(68.870)
$Treat \times Post_t^L$	–	–	–	–	365.936***
					(87.070)
ρ	0.186***	0.186***	0.186***	–	–
	(0.060)	(0.060)	(0.060)		
σ2	1.301***	1.301***	1.301***	–	–
	(0.090)	(0.090)	(0.090)		
Controls	yes	yes	yes	yes	yes
Province	yes	yes	yes	yes	yes
Year	yes	yes	yes	yes	yes
n	450	450	450	450	450

***significance level at 0.01; DID – difference-in-difference

Source: Author's compilation

https://doi.org/10.17221/412/2024-AGRICECON

efficiency. Third, there are spatial spillover effects of policy implementation, such as knowledge spillover and technical service spillover, which promoted the reduction of AFNSP in the region as a whole. Fourth, the three subsidies reform, aimed at mitigating the environmental effect of AFNSP, not only safeguarded the increase in grain yields but also exhibited a strengthening influence as time progressed. Fifth, the influence of the natural environment and farming culture made the effects of the three subsidies reform heterogeneous, with differences in implementation effects across regions.

Understanding the influencing mechanism between the three subsidies reform and AFNSP offers critical policy insights and serves as a reference for other nations. Firstly, considering the effect of the three subsidies reform on the AFNSP, the government can further adjust the reform direction of agricultural subsidies and the evaluation criteria for implementation, clarify specific guidelines, strengthen the requirements for land protection at the local government level and enhance policy and institutional standards. Secondly, China needs to improve the government subsidy allocation and regulatory system gradually, achieve precise subsidies and enhance the effectiveness of policy implementation. The green orientation of agricultural subsidies requires precise government subsidies to support it, and it is essential to promote the precise matching of government subsidy funds and subsidy recipients. In addition, a platform for policy interaction should be established to promote the coordinated implementation of agricultural policies and cross-regional collaboration of agricultural resources, strengthening the overall effectiveness of policy implementation. Finally, China's trends in agricultural subsidy policy reform align with the emphasis in the EU and the United States on environmental aspects of agriculture. The EU's CAP and the U.S. EQIP use green payment schemes and agri-environmental subsidies within direct fiscal support frameworks to enhance producers' environmental stewardship, incentivising reductions in agricultural pollution and improvements in ecological quality. China, following its strategic emphasis on agricultural ecological sustainability, has adopted comparable direct subsidy mechanisms for behavioural incentivisation. Through restructuring under the three subsidies reform agenda, the nation has required reductions in agricultural production contaminants and strengthening soil fertility conservation in cultivated lands. As a developing country, China's agricultural subsidy reforms can reduce AFNSP and improve agroecological quality, providing a reference for other developing countries, particularly those in South Asia and Southeast Asia that are close to China, in adjusting their agricultural subsidy policies.

Our study had some limitations, but the results also point to future research directions. First, in this research, we used AFNSP to analyse the environmental effect of agricultural subsidy reform – namely, the three subsidies reform. However, there are still many meaningful policies, such as China's rural revitalisation and guiding social capital investment in rural areas. The effectiveness of these policies should be tested in the future. Second, this study is based on the background of China. On the one hand, there are differences in rice and wheat cultivation in China, leading to differences in values, which can be classified in the future. On the other hand, we do not have sufficient evidence to suggest that our study can be generalised worldwide so that we can use data from other countries for validation in the future. Third, the data we selected were macro data, which revealed the effect of the three subsidies reform on agricultural pollution, but individual characteristics within the provinces are prone to convergence. In the future, to explore the effects of the policy, we can use micro data, such as matching farmers' evaluations and perceptions of the three subsidies policy with their behaviour. Finally, there are significant differences in the level of agricultural development between China and Western countries. The proportion of rural labour force employed in agriculture remains relatively high, and current available data do not show an inverted U-shaped effect of agricultural subsidy policies. As China's agriculture continues to develop in the future, it may potentially follow patterns similar to those observed in developed countries in Europe and America, and this hypothesis requires future verification.

Acknowledgement: The authors express their gratitude to reviewers of this journal for providing valuable comments and suggestions that enhanced the merit of this paper.

REFERENCES

Adom P.K., Adams S. (2020): Decomposition of technical efficiency in agricultural production in Africa into transient and persistent technical efficiency under heterogeneous technologies. World Development, 129: 04907.

https://doi.org/10.17221/412/2024-AGRICECON

Bai J., Wang Y., Sun W. (2022): Exploring the role of agricultural subsidy policies for sustainable agriculture based on Chinese agricultural big data. Sustainable Energy Technologies and Assessments, 53: 102473.

Baumhardt R.L., Jones O.R., Schwartz R.C. (2008): Long-term effects of profile-modifying deep plowing on soil properties and crop yield. Soil Science Society of America Journal, 72: 677–682.

Bhorat H., Kanbur R., Stanwix B. (2014): Estimating the impact of minimum wages on employment, wages, and non-wage benefits: The case of agriculture in South Africa. American Journal of Agricultural Economics, 96: 1402–1419.

Callaway B., Sant'Anna P.H. (2021): Difference-in-differences with multiple time periods. Journal of econometrics, 225: 200–230.

Cao Y., Bai Y., Zhang L. (2024): Do the types of agricultural socialized services and their diverse suppliers matter to farmland renting in rural China? Journal of Asian Economics, 94: 101763.

Cassell CA., Dreher L.M., Myers L.A. (2013): Reviewing the SEC's review process: 10-K comment letters and the cost of remediation. The Accounting Review, 88: 1875–1908.

Chen Y., Fan Z., Gu X., Zhou L.A. (2020): Arrival of young talent: The send-down movement and rural education in China. American Economic Review, 110: 3393–3430.

Chen Y.H., Wen X.W., Wang B., Nie P.Y. (2017): Agricultural pollution and regulation: How to subsidize agriculture? Journal of Cleaner Production, 164: 258–264.

Ciaian P., Baldoni E., Kancs D.A., Drabik D. (2021): The capitalization of agricultural subsidies into land prices. Annual Review of Resource Economics, 13: 17–38.

Coderoni S., Esposti R. (2018): CAP payments and agricultural GHG emissions in Italy. A farm-level assessment. Science of the Total Environment, 627: 427–437.

Duan J., Ren C., Wang S., Zhang X., Reis S., Xu J., Gu B. (2021): Consolidation of agricultural land can contribute to agricultural sustainability in China. Nature Food, 2: 1014–1022.

Fan P., Mishra A.K., Feng S., Su M. (2023a): The effect of agricultural subsidies on chemical fertilizer use: Evidence from a new policy in China. Journal of Environmental Management, 344: 118423.

Fan P., Mishra A.K., Feng S., Su M., Hirsch S. (2023b): The impact of China's new agricultural subsidy policy on grain crop acreage. Food Policy, 118: 102472.

Gocht A., Ciaian P., Bielza M., Terres J.M., Röder N., Himics M., Salputra G. (2017): EU-wide economic and environmental impacts of CAP greening with high spatial and farm-type detail. Journal of Agricultural Economics, 68: 651–681.

Guo J., Li C., Xu X., Sun M., Zhang L. (2022): Farmland scale and chemical fertilizer use in rural China: New evidence from the perspective of nutrient elements. Journal of Cleaner Production, 376: 134278.

Guo L., Li H., Cao X., Cao A., Huang M. (2021): Effect of agricultural subsidies on the use of chemical fertilizer. Journal of Environmental Management, 299: 113621.

Hennessy D.A. (1998): The production effects of agricultural income support policies under uncertainty. American Journal of Agricultural Economics, 80: 46–57.

Hou M.Y., Yao S.B. (2019): EKC retest of fertilizer non-point source pollution emission under heterogeneous conditions – Grouping based on panel threshold model. Journal of Agrotechnical Economics, 4: 104–118. (in Chinese)

Hu Y., Liu Y. (2024): Impact of fertilizer and pesticide reductions on land use in China based on crop-land integrated model. Land Use Policy, 141: 107155.

Kansanga M., Andersen P., Kpienbaareh D., Mason-Renton S., Atuoye K., Sano Y., Antabe R., Luginaah I. (2019): Traditional agriculture in transition: Examining the impacts of agricultural modernization on smallholder farming in Ghana under the new Green Revolution. International Journal of Sustainable Development & World Ecology, 26: 11–24.

Karplus V.J., Wu M. (2023): Dynamic responses of SO_2 pollution to China's environmental inspections. Proceedings of the National Academy of Sciences, 120: e2214262120.

Ke C., Huang S.Z. (2024): The effect of environmental regulation and green subsidies on agricultural low-carbon production behavior: A survey of new agricultural management entities in Guangdong Province. Environmental Research, 242: 117768.

Kirwan B.E., Roberts M.J. (2016): Who really benefits from agricultural subsidies? Evidence from field-level data. American Journal of Agricultural Economics, 98: 1095–1113.

Laborde D., Mamun A., Martin W., Piñeiro V., Vos R. (2021): Agricultural subsidies and global greenhouse gas emissions. Nature Communications, 12: 2601.

Lee C.C., Zeng M., Luo K. (2024): How does climate change affect food security? Evidence from China. Environmental Impact Assessment Review, 104: 107324.

Li N., Zhou Q. Y. (2023): The spillover effect of the withdrawal of counties into districts on regional grain production. Chinese Rural Economy, 5: 23–41. (in Chinese)

Li Q., Wang J., Wu J., Zhai Q. (2023): The dual impacts of specialized agricultural services on pesticide application intensity: Evidence from China. Pest Management Science, 79: 76–87.

Liang, W. J., Wang, K. C. A., Chou, P. Y. (2018): The superiority among specific, demand ad valorem and cost ad valorem subsidy regimes. Journal of Economics, 123: 1–21.

Liu Q., Wang Y. (2024): The effect of rice-planting culture on fellow townsman co-residence of migrant workers:

https://doi.org/10.17221/412/2024-AGRICECON

From the perspective of social networks. Chinese Rural Economy, 8: 107–124. (in Chinese)

Liu P., Wang Y., Zhang W. (2023): The influence of the Environmental Quality Incentives Program on local water quality. American Journal of Agricultural Economics, 105: 27–51.

Liu T., Xu H. (2023): Post-assessment in policy-based strategic environmental assessment: Taking China's agricultural support and protection subsidy policy as an example. Environmental Impact Assessment Review, 100: 107047.

Liu Y., Yan B., Wang Y., Zhou Y. (2019a): Will land transfer always increase technical efficiency in China? – A land cost perspective. Land Use Policy, 82: 414–421.

Liu Z., Yang D., Wen T. (2019b): Agricultural production mode transformation and production efficiency: A labor division and cooperation lens. China Agricultural Economic Review, 11: 160–179.

Marcus M., Sant'Anna P.H. (2021): The role of parallel trends in event study settings: An application to environmental economics. Journal of the Association of Environmental and Resource Economists, 8: 235–275.

Meng M., Zhang W., Zhu X., Shi Q. (2024): Agricultural mechanization and rural worker mobility: Evidence from the Agricultural Machinery Purchase Subsidies programme in China. Economic Modelling, 139: 106784.

Nie P.Y., Yang Y.C., Chen Y.H., Wang Z.H. (2016): How to subsidize energy efficiency under duopoly efficiently? Applied Energy, 175: 31–39.

Nie Z., Dong T., Pan W. (2024): Spatial differentiation and geographical similarity of traditional villages – Take the Yellow River Basin and the Yangtze River Basin as examples. PloS ONE, 19: e0295854.

Niu Z., Yi F., Chen C. (2022): Agricultural insurance and agricultural fertilizer non-point source pollution: Evidence from China's policy-based agricultural insurance pilot. Sustainability, 14: 2800.

Pourzand F., Bakhshoodeh M. (2014): Technical efficiency and agricultural sustainability – Technology gap of maize producers in Fars province of Iran. Environment, Development and Sustainability, 16: 671–688.

Ren C., Liu S., van Grinsven H., Reis S., Jin S., Liu H., Gu B. (2019): The impact of farm size on agricultural sustainability. Journal of Cleaner Production, 220: 357–367.

Repetto R. (1987): Economic incentives for sustainable production. The Annals of Regional Science, 21: 44–59.

Selinger T.J. (1993): Canada's environmental review of the North American free trade agreement. Journal of Professional Issues in Engineering Education and Practice, 119: 246–253.

Sha Z., Ren D., Li C., Wang Z. (2024): Agricultural subsidies on common prosperity: Evidence from the Chinese social survey. International Review of Economics & Finance, 91: 1–18.

Sun P., Nie P.Y. (2015): A comparative study of feed-in tariff and renewable portfolio standard policy in renewable energy industry. Renewable Energy, 74: 255–262.

Talhelm T., Zhang X., Oishi S., Shimin C., Duan D., Lan X., Kitayama S. (2014). Large-scale psychological differences within China explained by rice versus wheat agriculture. Science, 344: 603–608.

Tang C.S., Wang Y., Zhao M. (2024): The impact of input and output farm subsidies on farmer welfare, income disparity, and consumer surplus. Management Science, 70: 3144–3161.

Tang K., Gong C., Wang D. (2016): Reduction potential, shadow prices, and pollution costs of agricultural pollutants in China. Science of the Total Environment, 541: 42–50.

Tang K., He C., Ma C., Wang D. (2019): Does carbon farming provide a cost-effective option to mitigate GHG emissions? Evidence from China. Australian Journal of Agricultural and Resource Economics, 63: 575–592.

Walls H.L., Johnston D., Tak M., Dixon J., Hanefeld J., Hull E., Smith R.D. (2018): The impact of agricultural input subsidies on food and nutrition security: A systematic review. Food Security, 10: 1425–1436.

Xu M., Chen C., Ahmed M.A. (2024): Market-oriented farmland transfer and outsourced machinery services: Evidence from China. Economic Analysis and Policy, 81: 1214–1226.

Xue L., Hou P., Zhang Z., Shen M., Liu F., Yang L. (2020): Application of systematic strategy for agricultural non-point source pollution control in Yangtze River basin, China. Agriculture, Ecosystems & Environment, 304: 107148.

Yang B., Zhan X., Tian Y. (2021): Evaluation on the effect of the transformation policy of resource-exhausted cities – An empirical analysis based on the difference-in-difference model. Energy Reports, 7: 959–967.

Yang J., Gunderson M. (2020): Minimum wage impacts on wages, employment and hours in China. International Journal of Manpower, 41: 207–219.

Yang, Q., Peng, C., Xu, Q. (2022): Does agricultural 'three subsidies' reform promote farmers' land transfer? Chinese Rural Economy, 5: 89–106. (in Chinese)

Yi F., Sun D., Zhou Y. (2015): Grain subsidy, liquidity constraints and food security – Impact of the grain subsidy program on the grain-sown areas in China. Food Policy, 50: 114–124.

You H., Li J., Xu F. (2024): Off-farm employment and nonpoint source pollution from chemical fertilizers in China: Mediating role of farmland transfer. Environment, Development and Sustainability, 1–18.

https://doi.org/10.17221/412/2024-AGRICECON

Zhan H.B., Hu Q. (2017): Farm size, market incentive and farmers' fertilization behavior. Journal of Agrotechnical Economics, 11: 72–79. (in Chinese)

Zhang J., Mishra A.K., Hirsch S., Li X. (2020): Factors affecting farmland rental in rural China: Evidence of capitalization of grain subsidy payments. Land Use Policy, 90: 104275.

Zhang R., Ma W., Liu J. (2021): Impact of government subsidy on agricultural production and pollution: A game-theoretic approach. Journal of Cleaner Production, 285: 124806.

Zhang Z. (2024): Do agricultural subsidies raise the income of rural households effectively? Evidence from rural China. Applied Economics Letters, 31: 958–966.

Zhang Z., Chen Y. H., Mishra A. K., Ni M. (2025). Effects of agricultural subsidy policy adjustment on carbon emissions: A quasi-natural experiment in China. Journal of Cleaner Production, 487: 144603.

Zheng Z., Cheng S., Henneberry S.R. (2023): Total factor productivity change in China's grain production sector: 1980–2018. Australian Journal of Agricultural and Resource Economics, 67: 38–55.

Zhou W., Xue P., Xu D. (2024): Exploring disparities in employment location and structure: The influence of off-farm employment on reducing chemical fertilizer usage. Journal of Cleaner Production: 440: 140720.

Zhu M., Zheng K., Liu B., Jin F. (2024): Can agricultural support and protection subsidy policies promote high-quality development of grain industry? A case study of China. Agriculture, 14: 1664.

Received: October 29, 2024
Accepted: May 23, 2025
Published online: September 19, 2025