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Distributional welfare effects of agricultural subsidy reform in rural China using macro-micro simulation

Xiaobo Dong¹✉

This study evaluates the distributional welfare effects of agricultural subsidy reforms in rural China using an integrated macro-micro simulation approach. By combining a computable general equilibrium (CGE) model with an arithmetic microsimulation model based on household survey data, we analyze the impacts of different subsidy policies on rural household welfare. Using data from multiple sources, including the China Household Income Project (CHIP) survey, we simulate three policy scenarios: a baseline scenario maintaining the current system, a reform scenario shifting from input subsidies to direct subsidies, and a targeted scenario prioritizing support for low-income and smallholder farmers. The results show that the current subsidy system has a progressive distribution effect but can be improved through reforms. The targeted scenario achieves the greatest welfare gains for vulnerable groups (defined as low-income households and smallholder farmers), with the poorest households experiencing 50% higher net welfare effects compared to the baseline. Our findings suggest that shifting towards direct income support and prioritizing vulnerable groups can enhance the equity and effectiveness of China's agricultural subsidy policy while promoting inclusive rural development and poverty reduction.

¹China Cooperative Research Institute, Anhui University of Finance and Economics, Bengbu, China. ✉email: bim1314@126.com

Introduction

Agricultural subsidies represent a cornerstone of rural development policies worldwide, with governments allocating substantial resources to support farm incomes, enhance food security, and reduce rural poverty (International Monetary Fund 2024). Global agricultural support to individual producers reached \$540 billion annually in 2018–2020 according to OECD estimates, with developing countries increasingly adopting comprehensive subsidy programs to modernize their agricultural sectors (Laborde et al. 2021). However, the design and implementation of these policies face common challenges across countries, including inefficient resource allocation, uneven benefit distribution, and limited targeting of vulnerable populations (specifically low-income households and smallholder farmers with limited land holdings) (Guyomard et al. 2023).

Agriculture has been a critical sector for China's economic development and social stability. Over the past few decades, the Chinese government has implemented various agricultural subsidy policies to support farmers and ensure food security, following global trends while adapting to its unique institutional context (Huang et al. 2011).

These policies have played a vital role in promoting agricultural production, increasing farmers' incomes, and reducing rural poverty (Liu and Chen 2022). However, China's evolving economic and social landscape necessitates reforming the existing agricultural subsidy system to improve targeting of vulnerable groups and achieve more equitable benefit distribution (Zhang et al. 2023).

The current agricultural subsidy policies in China primarily include direct subsidies for grain production, comprehensive subsidies for agricultural inputs, subsidies for improved crop varieties, and subsidies for agricultural machinery (Ministry of Agriculture and Rural Affairs 2022). While these policies have contributed to the modernization of agriculture and the improvement of farmers' livelihoods, they have also faced challenges such as inefficient allocation of resources, uneven distribution of benefits, and limited impact on smallholder farmers (Wang et al. 2021; Li et al. 2020).

Assessing the distributional welfare effects of agricultural subsidy reforms is crucial for policymakers to design more effective and inclusive policies (Barrett and Maxwell 2023). Previous studies have examined the impact of agricultural subsidies on various aspects, such as agricultural production (Goodwin and Smith 2013), farmers' incomes (Yu and Nin-Pratt 2014), and rural poverty (Fan et al. 2022). However, few studies have comprehensively analyzed the distributional welfare effects of agricultural subsidy reforms in China, particularly considering both macro and micro perspectives (Zhu et al. 2011).

This study aims to fill this research gap by evaluating the distributional welfare effects of agricultural subsidy reforms in rural China using a macro-micro simulation approach. The main objectives of this study are:

1. To assess the impact of current agricultural subsidy policies on the welfare of different types of rural households;
2. To simulate the distributional welfare effects of alternative agricultural subsidy reform scenarios;
3. To provide policy recommendations for designing more equitable and efficient agricultural subsidy policies in China.

To achieve these objectives, we employ a macro-micro simulation framework that combines a computable general equilibrium (CGE) model and a microsimulation model (Bourguignon et al. 2005). We analyze three policy scenarios: a baseline scenario maintaining the current subsidy structure with 30% direct subsidies and 70% input subsidies; a reform scenario shifting the

composition to 60% direct subsidies and 40% input subsidies while keeping total subsidy levels constant; and a targeted scenario allocating 80% to direct subsidies and 20% to input subsidies with a 20% increase in total funding, specifically prioritizing low-income and smallholder farmers. The CGE model captures the economy-wide effects of agricultural subsidy reforms, while the microsimulation model assesses the distributional impacts on different types of rural households (Chen et al. 2007). This integrated approach allows us to analyze the complex interactions between macroeconomic policies and household-level welfare outcomes (Lofgren et al. 2002).

The remainder of this paper is structured as follows. Section "Theoretical foundations and research methods" provides a review of the relevant literature on agricultural subsidy policies and their welfare effects. Section "Data sources and processing" describes the macro-micro simulation framework and the data used in this study. Section "Empirical analysis results" presents the results of the simulation analysis, including the impacts of current agricultural subsidy policies and the distributional welfare effects of alternative reform scenarios. Section "Conclusions and policy recommendations" discusses the policy implications of the findings and concludes the paper (Cockburn 2001).

Theoretical foundations and research methods

Theoretical foundations and literature review

Theoretical foundations of welfare effect evaluation. The evaluation of welfare effects is rooted in welfare economics principles, which examine resource allocation and income distribution within economies (Mas-Colell et al. 1995). The fundamental theorem of welfare economics states that, under certain conditions, a competitive market equilibrium leads to a Pareto-efficient allocation of resources (Arrow and Debreu 1954). However, market failures, such as externalities, public goods, and imperfect information, can result in suboptimal outcomes and justify government interventions, including agricultural subsidy policies (Stiglitz 2000).

The measurement of welfare effects typically involves the use of welfare indicators, such as consumer surplus, producer surplus, and social welfare (Just et al. 2004). These indicators can be derived from the analysis of supply and demand curves, which represent the behavior of producers and consumers in the market (Varian 2014). The change in welfare due to a policy intervention can be calculated by comparing the welfare indicators before and after the intervention (Kaldor 1939).

In the context of agricultural subsidy policies, the welfare effects can be evaluated at different levels, including the household level, the sectoral level, and the economy-wide level (Anderson and Martin 2005). At the household level, the welfare effects can be measured by changes in income, consumption, and poverty status (Deaton and Muellbauer 1980). At the sectoral level, the welfare effects can be assessed by changes in agricultural production, prices, and trade (Johnson 1973). At the economy-wide level, the welfare effects can be evaluated by changes in GDP, employment, and income distribution (Ruttan 2002).

Literature review on agricultural subsidy policy research. The research on agricultural subsidy policies has attracted significant attention from scholars worldwide. Numerous studies have investigated the impacts of agricultural subsidies on various aspects of the economy, including agricultural production, trade, income distribution, and environmental sustainability (OECD 2021; Sumner 2007; Orden et al. 2011).

In the context of China, several studies have examined the effects of agricultural subsidy policies on farmers' incomes and

agricultural production. Direct grain subsidies have been found to have a positive impact on grain production and farmers' incomes, though the impact varies across regions and farm sizes (Huang et al. 2013). Agricultural machinery subsidies have been shown to have a significant positive effect on the adoption of agricultural machinery (Yi et al. 2015).

Other studies have focused on the distributional effects of agricultural subsidies in China. Microsimulation analysis has shown that agricultural subsidies have a progressive effect on income distribution (Wang et al. 2018). CGE model analysis has demonstrated that subsidy reforms could lead to a more efficient allocation of resources and improve social welfare (Li et al. 2020). Recent studies have further advanced this research agenda, investigating the heterogeneous effects of agricultural subsidies across different farm sizes and finding that smallholder farmers benefit less from input subsidies compared to direct income support (Zhang et al. 2023). Productivity analysis has shown that shifting toward direct payments can enhance agricultural efficiency while maintaining rural incomes (Liu and Chen 2022).

However, despite the growing body of literature on agricultural subsidy policies in China, few studies have comprehensively evaluated the distributional welfare effects of agricultural subsidy reforms using a macro-micro simulation approach. For example, Huang et al. (2006) assessed the impacts of agricultural subsidies on crop production and farmers' incomes using a partial equilibrium model, but did not consider the economy-wide and distributional effects. Sun et al. (2015) analyzed the welfare implications of agricultural subsidy policies using a microsimulation model, but focused only on the poverty reduction effects without examining the broader economic impacts.

In the international context, agricultural subsidy reforms have been extensively studied across different countries and regions, providing valuable comparative insights. In the European Union, analysis has shown how environmental conditionality can be integrated with income support while maintaining distributional equity (Guyomard et al. 2023). In the United States, research on subsidized crop insurance programs has revealed significant heterogeneity in benefits across farm types, affecting both farm incomes and environmental outcomes (Goodwin and Smith 2013). In developing countries, several studies have investigated similar reform challenges. CGE model evaluation of agricultural price support policies in Mexico found that the policies were regressive and benefited large-scale farmers more than smallholders (Coady and Harris 2004). Examination of input subsidy programs in Malawi highlighted the challenges of achieving both efficiency and equity in subsidy distribution (Dorward and Chirwa 2011). Recent research in India analyzed the distributional effects of fertilizer subsidy reforms and found that direct benefit transfers improved targeting efficiency while reducing fiscal burdens (Kumar et al. 2021). Similarly, studies in Indonesia demonstrated that transitioning from fuel subsidies to agricultural direct payments enhanced welfare outcomes for rural households (Warr and Yusuf 2022).

Compared to these international studies, this research contributes to the literature in several important ways. Methodologically, we employ an integrated macro-micro simulation framework that captures both economy-wide effects through the CGE model and household-level distributional impacts through microsimulation, providing a more comprehensive assessment than single-model approaches. Contextually, we address the unique institutional features of China's rural economy, including the household responsibility system, fragmented land holdings, and imperfect factor markets, which differ substantially from conditions in other countries. Policy-wise, we analyze three specific reform scenarios tailored to China's current policy debate, offering concrete evidence for ongoing discussions about subsidy

restructuring. Furthermore, our analysis explicitly considers regional heterogeneity across China's diverse economic zones and examines differential impacts across farm sizes and income groups, providing nuanced insights for targeted policy design that can inform subsidy reforms in other developing countries facing similar challenges of balancing efficiency, equity, and sustainability in agricultural support systems.

The macro-micro simulation framework allows for a more holistic assessment of the economy-wide and distributional welfare effects, taking into account the complex linkages between agriculture, rural households, and the broader economy. Recent methodological advances have further strengthened these approaches. Studies have refined techniques for linking CGE and microsimulation models through iterative top-down bottom-up approaches that ensure convergence between macro and micro levels (Benkovskis et al. 2024). Research has also improved methods for incorporating behavioral responses and market imperfections specific to developing country contexts (Davies 2009). Analysis of China's recent agricultural subsidy reforms (2016–2020) has provided new empirical insights into the effects of shifting from input-linked subsidies to direct payments linked to actual cultivation, demonstrating positive impacts on farm productivity while reducing chemical fertilizer use (Fan and Yang 2024; Fan et al. 2023). These recent developments inform our modeling choices and enhance the policy relevance of our analysis. By providing a comparative analysis with previous studies and highlighting the methodological contributions, this study aims to enrich the understanding of agricultural subsidy policy impacts and inform evidence-based policy-making in China and other developing countries.

The theoretical foundation for this study can be expressed using the following general equilibrium model, which represents the economy-wide effects of agricultural subsidy policies. The social welfare maximization problem in the CGE framework is represented by:

$$\max \sum_{i=1}^n \alpha_i \log(C_i) \quad (1)$$

where the logarithmic utility function captures diminishing marginal utility of consumption, commonly used in welfare economics to represent consumer preferences with constant relative risk aversion.

subject to:

$$\sum_{i=1}^n p_i C_i = Y \quad (2)$$

where C_i is the consumption of good i , α_i is the share parameter for good i , p_i is the price of good i , and Y is the total income (Samuelson 1947).

The microsimulation model, which captures the distributional impacts on rural households, estimates household welfare using a linear index approach:

$$W_h = \sum_{i=1}^m \beta_i X_{hi} \quad (3)$$

where W_h represents the welfare level of household h measured in monetary terms, X_{hi} denotes observable household characteristics i (such as land size, education level, and demographic composition), and β_i represents the welfare weight of each characteristic estimated through econometric methods using household survey data (Aaberge and Colombino 2013).

By combining these two models, this study aims to provide a comprehensive assessment of the distributional welfare effects of agricultural subsidy reforms in rural China.

Research methods and model construction

Computable general equilibrium (CGE) model. The CGE model used in this study is based on the standard PEP-1-1 model developed by Decaluwé et al. (2012). The model is calibrated to the latest available Chinese Social Accounting Matrix (SAM) for the year 2017, which is constructed using data from the National Bureau of Statistics of China (National Bureau of Statistics of China 2018).

The production structure of the model assumes that each sector produces a single output using a combination of intermediate inputs and primary factors (capital and labor) based on a nested Constant Elasticity of Substitution (CES) function (Arrow et al. 1961). The production function for each sector j can be represented as:

$$X_j = A_j \left[\alpha_j K_j^{\rho_j} + (1 - \alpha_j) L_j^{\rho_j} \right]^{\frac{1}{\rho_j}} \quad (4)$$

where X_j is the output of sector j , A_j is the total factor productivity, K_j , L_j , and T_j are the capital, labor, and land inputs respectively, α_j , β_j , and γ_j are the share parameters with $\alpha_j + \beta_j + \gamma_j = 1$, and ρ_j is the substitution parameter. The inclusion of land as a separate factor is particularly important for agricultural sectors where land represents a significant portion of production costs (Hertel 1997).

To better reflect Chinese rural market realities, we adapt the standard CGE framework to incorporate several institutional features and market imperfections characteristic of China's agricultural economy. First, we introduce labor mobility constraints by adding migration costs between rural and urban sectors, recognizing that household registration (hukou) system and social welfare restrictions impede perfect labor mobility (Meng 2012). Second, we model imperfect land markets by constraining land transfers and incorporating transaction costs, reflecting the limited development of rural land rental markets and the collective ownership system (Deininger et al. 2014). Third, we account for credit constraints faced by rural households by limiting their borrowing capacity based on collateral availability, as formal financial institutions remain less accessible in rural areas (Turvey et al. 2010). Fourth, we incorporate information asymmetries in agricultural input markets by adjusting price transmission elasticities between wholesale and retail levels, reflecting the challenges smallholders face in accessing market information (Qiu et al. 2012). These adaptations are calibrated using China-specific parameters derived from recent empirical studies and are validated through sensitivity analyses presented in Section "Robustness checks and sensitivity analysis". While these modifications improve the model's realism, we acknowledge that some simplifications remain, and we discuss the implications of these assumptions for our results in the robustness checks and limitations sections.

Households' consumption behavior is modeled using the Linear Expenditure System (LES), which assumes that households allocate their disposable income to different commodities according to a fixed set of expenditure shares (Stone 1954). The LES function for each household h can be expressed as:

$$C_{h,i} = \gamma_{h,i} + \frac{\beta_{h,i}}{P_i} \left(Y_h - \sum_{j=1}^n P_j \gamma_{h,j} \right) \quad (5)$$

where $C_{h,i}$ is the consumption of commodity i by household h , $\gamma_{h,i}$ is the subsistence level of consumption, $\beta_{h,i}$ is the marginal budget share, P_i is the price of commodity i , and Y_h is the disposable income of household h (Lluch et al. 1977).

The model also includes a set of equilibrium conditions, such as the equality between supply and demand in each market, the balance of payments, and the government budget constraint

(Shoven and Whalley 1992). These conditions ensure the consistency and coherence of the model results.

Microsimulation model of rural household income distribution. To analyze the distributional impacts of agricultural subsidy reforms on rural households, we develop a microsimulation model that is linked to the CGE model (Bourguignon et al. 2005). The microsimulation model uses data from the China Household Income Project (CHIP) survey for the year 2018, which provides detailed information on the income sources and characteristics of rural households (Li et al. 2008).

The income of each rural household h is decomposed into four main components: agricultural income ($Y_{h,a}$), wage income ($Y_{h,w}$), transfer income ($Y_{h,t}$), and other income ($Y_{h,o}$) (Benjamin et al. 2008). The total income of household h can be expressed as:

$$Y_h = Y_{h,a} + Y_{h,w} + Y_{h,t} + Y_{h,o} \quad (6)$$

The agricultural income of each household is further disaggregated into income from different agricultural activities, such as crop cultivation, livestock raising, and forestry (Ravallion and Chen 2007). The income from each agricultural activity k is determined by the corresponding output price (P_k), output quantity ($Q_{h,k}$), and subsidies received ($S_{h,k}$):

$$Y_{h,a} = \sum_{k=1}^K (P_k Q_{h,k} + S_{h,k}) \quad (7)$$

The microsimulation model also includes a set of equations that capture the relationships between household characteristics (e.g., age, education, and land size) and income components (Heckman 1979). These equations are estimated using econometric techniques, such as ordinary least squares (OLS) and Tobit regressions (Tobin 1958).

The CGE model and the microsimulation model are linked through a set of transmission channels represented by the following equations:

$$P_i^{micro} = f(P_i^{CGE}, wage^{CGE}, employment^{CGE}) \quad (8)$$

$$Y_h^{micro} = g(P_i^{micro}, wage^{CGE}, subsidy_h) \quad (9)$$

where P_i^{micro} represents commodity prices used in the microsimulation model, P_i^{CGE} denotes prices from the CGE model, $wage^{CGE}$ is the wage rate from the CGE simulation, $employment^{CGE}$ represents employment levels, and $subsidy_h$ denotes household-specific subsidy amounts. The changes in these variables obtained from the CGE model simulations are passed to the microsimulation model to estimate the distributional impacts on rural households (Cogneau and Robilliard 2000; Savard 2003).

We recognize that standard microsimulation models typically assume exogenous household behavior, which may introduce bias when estimating welfare effects of policy changes that affect production, consumption, and labor supply decisions. To address this endogeneity concern, we implement an iterative linking procedure between the macro and micro models (Savard 2010). Specifically, after obtaining initial results from the CGE model, we pass the price and wage changes to the microsimulation model, which then estimates household-level behavioral responses using elasticity parameters derived from the CHIP survey data. These aggregated behavioral adjustments are fed back into the CGE model to re-equilibrate markets, and this iteration continues until convergence is achieved (typically within 3–5 iterations). Additionally, we incorporate behavioral response functions in the microsimulation component that allow household labor supply, consumption patterns, and agricultural production decisions to adjust to changes in relative prices and incomes

Table 1 Model parameter settings.

Parameter	Description	Value	Source
α_j	Capital share parameter	0.3-0.7	SAM and literature
ρ_j	Substitution parameter	0.5-1.5	Literature
$\beta_{h,i}$	Marginal budget share	0.1-0.6	CHIP survey
$\gamma_{h,i}$	Subsistence level of consumption	50-500 yuan	CHIP survey
τ_a	Agricultural income tax rate	0.05	Government policy
τ_w	Wage income tax rate	0.03-0.45	Government policy
τ_c	Consumption tax rate	0.13	Government policy
τ_m	Import tariff rate	0.05-0.25	Government policy

Table 2 Policy scenario descriptions.

Scenario	Direct subsidies	Input subsidies	Target group	Total subsidy level	Key features
Baseline	30%	70%	All farmers	Current level	Maintains existing subsidy structure
Reform	60%	40%	All farmers	Current level	Shifts toward direct income support
Targeted	80%	20%	Low-income & smallholder farmers	+20% increase	Prioritizes vulnerable groups

(Cogneau and Robilliard 2008). The elasticity parameters governing these responses are econometrically estimated using the CHIP household panel data, ensuring that our model captures realistic behavioral adjustments rather than assuming fixed behavioral patterns. We validate this approach through sensitivity analyses that compare results under different behavioral assumptions, demonstrating that our findings are robust to reasonable variations in response elasticities.

Model parameters and sectoral classification. The key parameters used in the CGE model are presented in Table 1. These parameters are calibrated using data from various sources, including the SAM, the National Bureau of Statistics of China, and existing literature (McDougall et al. 1998).

The sectors in the CGE model are classified based on the input-output table of China (United Nations 2008). The model includes 10 sectors covering agriculture, industry, and services: Agriculture (AGR) includes crop cultivation, livestock raising, forestry, and fishery; Mining (MIN) covers coal, oil, natural gas, and other mineral extraction; Manufacturing (MAN) encompasses food processing, textiles, chemicals, and machinery; Electricity and gas (ELE) includes power generation and distribution; Construction (CON) covers building activities; Trade and transport (TRD) includes wholesale, retail, and transportation services; Hospitality and catering (HOS) covers hotels and restaurants; Financial services (FIN) includes banking and insurance; Real estate (REA) covers property development and management; and Other services (OTH) includes education, healthcare, and public administration. Detailed sectoral classification information is provided in Supplementary Material Table S1.

By combining the CGE model and the microsimulation model, this study aims to provide a comprehensive assessment of the distributional welfare effects of agricultural subsidy reforms in rural China (Cockburn et al. 2010). The model results will shed light on the potential winners and losers of different reform scenarios and inform the design of more effective and equitable agricultural policies (Davies 2009). Table 2 presents the detailed characteristics of the three policy scenarios analyzed in this study.

To capture the dynamic effects of agricultural subsidy reforms, we extend the standard CGE model to a recursive dynamic framework that allows for capital accumulation, labor market adjustments, and productivity growth over time (Thurlow 2004). The dynamic CGE model is calibrated using a sequence of SAMs for multiple years and linked with the microsimulation model

through an iterative process (Lofgren and Robinson 2004). The enhanced macro-micro simulation framework enables us to analyze the long-term distributional welfare effects of subsidy policies and capture the complex interactions between agriculture, rural households, and the broader economy.

Furthermore, we incorporate heterogeneous household behaviors into the microsimulation model by estimating household-specific parameters for consumption, production, and labor supply decisions using the CHIP survey data (Haddad and Hewings 2005). The heterogeneous microsimulation approach allows us to better represent the diversity of rural households and capture the differential impacts of subsidy reforms on different household types (Orcutt et al. 1976).

Compared to simpler methods, such as partial equilibrium models or aggregate analysis, the enhanced macro-micro simulation framework offers several advantages. First, it provides a more comprehensive and integrated assessment of the economy-wide and distributional effects of agricultural subsidies by considering the linkages and feedback effects between different sectors and agents. Second, it allows for a more realistic representation of the heterogeneity and dynamics of rural households and agricultural systems, which are crucial for understanding the distributional impacts of policy changes. Third, it enables us to simulate and compare alternative subsidy reform scenarios and identify the optimal policy mix for achieving multiple objectives, such as efficiency, equity, and sustainability.

However, the enhanced macro-micro simulation approach also has some limitations and challenges. It requires a large amount of data from various sources and involves complex modeling and computation procedures, which may limit its applicability and transparency. The model results are sensitive to the assumptions and parameters used, and thus require careful sensitivity analysis and robustness checks. The macro-micro linkages and feedback effects may be difficult to validate and interpret, and the model may not capture all the relevant factors and mechanisms influencing agricultural subsidy policies and rural welfare.

Despite these challenges, the enhanced macro-micro simulation framework represents a significant methodological advancement in the analysis of agricultural subsidy reforms and their distributional welfare effects. By providing a more comprehensive, dynamic, and disaggregated assessment, this study contributes to a deeper understanding of the complex policy issues and trade-offs involved in reforming China's agricultural subsidy

system. The improved methodology can also serve as a valuable tool for evidence-based policy-making and be adapted to other developing country contexts facing similar challenges in agricultural and rural development.

Data sources and processing

Data collection and preprocessing. The data used in this study are obtained from various sources, including the National Bureau of Statistics of China, the Ministry of Agriculture and Rural Affairs, and the China Household Income Project (CHIP) survey. The primary data sources include: the 2017 Social Accounting Matrix constructed from input-output tables and national accounts; agricultural production and price data from the Ministry of Agriculture and Rural Affairs covering 2000–2020; the 2018 CHIP survey with 20,000 rural households providing detailed income and expenditure information; agricultural subsidy program data from the Ministry of Finance for 2000–2020; rural population and employment statistics from the National Bureau of Statistics; and tax and tariff rate data from the State Taxation Administration. Complete data source documentation is provided in Supplementary Material Table S2.

The SAM is a comprehensive dataset that captures the economic transactions between different sectors and agents in the economy for a given year (Pyatt and Round 1985). The SAM used in this study is constructed based on the 2017 input-output table and national income and product accounts published by the National Bureau of Statistics of China, while the CHIP survey data are from 2018. We acknowledge that using data from 2017 to 2018 introduces a time lag relative to the current period, but this is justified by several considerations. First, China's agricultural economic structure changes gradually, with no major structural breaks occurring between 2017 and 2020, ensuring that the fundamental relationships captured in our model remain valid. Second, the 2018 CHIP survey represents the most recent nationally representative household dataset available for research purposes, as subsequent waves have not yet been released for academic use. Third, we adjust key macroeconomic aggregates in the SAM (such as GDP, employment, and price levels) to match 2018 values, ensuring consistency between the macro and micro data. Fourth, this one-year difference between SAM and household survey data is consistent with established practices in macro-micro simulation studies internationally (Robinson et al. 2001). To further validate our approach, we conduct three additional validation exercises. First, we compare our baseline model predictions with actual agricultural subsidy outcomes reported in the Ministry of Agriculture's 2019 and 2020 statistical bulletins, finding that our model accurately predicts aggregate subsidy distribution patterns within 4% deviation for major categories. Second, we analyze whether any structural breaks occurred in China's agricultural economy between 2017–2018 and 2020 using Chow tests on key indicators (agricultural GDP growth, rural income growth, subsidy expenditure growth), finding no significant structural breaks ($p > 0.10$ for all tests), confirming the stability of underlying relationships. Third, we conduct a sensitivity analysis using updated 2019–2020 macroeconomic parameters (GDP growth rates, employment shares, price indices) and find that welfare effect estimates change by less than 6% compared to baseline results, well within acceptable bounds for policy simulation studies. Furthermore, we argue that focusing on pre-pandemic data (2017–2018) provides analytical advantages for assessing structural policy reforms. The COVID-19 pandemic introduced unprecedented temporary shocks that would confound the identification of long-term policy effects. Post-2020 data reflect a mixture of permanent structural trends and temporary pandemic-related disruptions, making it difficult to

isolate the impact of subsidy policy changes. Our pre-pandemic baseline provides a stable structural benchmark for evaluating policy reforms that are designed for long-term implementation rather than crisis response. As demonstrated in recent CGE modeling practice, using pre-shock baseline data is methodologically appropriate when analyzing structural policy reforms intended to operate over decades rather than responding to transitory events (Buddelmeyer et al. 2012). We acknowledge that our results should be interpreted as estimates of subsidy reform effects under normal economic conditions rather than crisis scenarios. Future research should indeed update this analysis with post-pandemic household survey data (currently unavailable for research use) to assess whether the distributional impacts of agricultural policies have fundamentally changed. However, preliminary aggregate data suggest that the relative position of different household groups and regions remained relatively stable through 2020, supporting the continued relevance of our findings for policy design.

The data on agricultural production and prices are collected from the statistical yearbooks and databases maintained by the Ministry of Agriculture and Rural Affairs. These data cover various agricultural commodities, including grains, vegetables, fruits, and livestock products, and are used to calibrate the production functions in the CGE model (Ministry of Agriculture and Rural Affairs 2019).

The CHIP survey is a nationally representative survey that collects detailed information on the income, expenditure, and socio-economic characteristics of rural households in China. The survey adopts a stratified and multi-stage sampling design, with a sample size of around 20,000 households in 2018 (Gustafsson et al. 2008). The survey data are used to construct the microsimulation model and analyze the distributional impacts of agricultural subsidy reforms on rural households.

The data on agricultural subsidy programs are obtained from the budget reports and policy documents published by the Ministry of Finance. These data provide information on the scale, structure, and distribution of different types of agricultural subsidies, such as direct subsidies, input subsidies, and price support (Ministry of Finance 2020).

The data on rural population and employment are sourced from the statistical yearbooks and bulletins released by the National Bureau of Statistics of China. These data are used to calibrate the labor market equations in the CGE model and to assess the employment effects of agricultural subsidy reforms (National Bureau of Statistics of China 2019).

The preprocessing steps include data cleaning, outlier detection, missing value imputation, and variable transformation (Little and Rubin 2019). The cleaned and processed data are then organized into a format suitable for model calibration and estimation.

Descriptive statistics are calculated for the key variables used in the study, such as agricultural production, household income, and subsidy distribution. These statistics provide an overview of the patterns and trends in the data and help identify potential issues or anomalies (Gujarati and Porter 2009).

The data sources and preprocessing methods described above ensure the reliability and validity of the analysis conducted in this study. By combining macro-level data from the SAM and micro-level data from the CHIP survey, the study is able to capture both the economy-wide and distributional effects of agricultural subsidy reforms in China (Cororaton and Cockburn 2007).

Sample characteristics analysis. The CHIP survey data provide a wealth of information on the socio-economic characteristics of rural households in China. In this section, we analyze the basic

Table 3 Sample characteristics statistics.

Characteristic	Sample Size	Proportion (%)	Mean	Standard deviation
Household size	20,000	100.0	3.8	1.6
Age of household head	20,000	100.0	52.3	12.5
Education level of household head (years)	20,000	100.0	7.2	3.4
Cultivated land area (mu)	18,500	92.5	4.5	3.7
Agricultural income share (%)	20,000	100.0	35.6	28.2
Subsidy income share (%)	16,000	80.0	5.2	6.8

features and distribution of the sample households to gain insights into their demographic profiles, income sources, and agricultural activities.

Table 3 presents the summary statistics of the key characteristics of the sample households. The total sample size is 20,000 households, representing different regions and income levels in rural China.

The average household size is 3.8 persons, with a standard deviation of 1.6, indicating that most rural households are relatively small. The age of the household head ranges from 20 to 90 years old, with an average of 52.3 years and a standard deviation of 12.5 years, suggesting a moderate level of age diversity among the sample households (Khan and Riskin 2001).

The education level of the household head is measured by the number of years of schooling. The average education level is 7.2 years, with a standard deviation of 3.4 years, implying that the majority of household heads have completed primary education or lower secondary education (Knight and Song 2005).

Cultivated land is a crucial factor in agricultural production. Among the sample households, 92.5% possess cultivated land, with an average area of 4.5 mu (1 mu \approx 0.067 hectares) and a standard deviation of 3.7 mu. This suggests that most rural households are smallholder farmers with limited land resources (Rozelle and Swinnen 2004).

The income structure of rural households is characterized by the shares of agricultural income and subsidy income in total household income. On average, agricultural income accounts for 35.6% of total income, with a standard deviation of 28.2%, indicating a significant variation in the importance of agricultural activities across households. Subsidy income, which includes various types of agricultural subsidies, has an average share of 5.2% and a standard deviation of 6.8%, suggesting that subsidies play a relatively minor role in the income portfolio of most rural households (Park et al. 2002).

Further analysis reveals substantial heterogeneity in household characteristics across regions, farm sizes, and grain production zones. To provide granular insights, we classify households along multiple dimensions. Geographically, we select representative provinces from each region: Jiangsu (Eastern), Henan (Central), and Guizhou (Western). Households in Guizhou exhibit significantly lower education levels (5.8 years vs. 8.4 years in Jiangsu) and smaller land holdings (3.2 mu vs. 5.1 mu in Jiangsu) compared to eastern and central provinces. By farm size, we categorize households into four groups: very small (<2 mu, 35% of sample), small (2–5 mu, 40%), medium (5–10 mu, 18%), and large (>10 mu, 7%). Very small and small farmers, who constitute 75% of rural households, have limited mechanization access and higher per-unit production costs. We also distinguish between major grain-producing regions (Henan, Heilongjiang, Shandong, accounting for 45% of national grain output) and non-major grain regions, as subsidy policies differentially affect these areas. Major grain-producing households receive higher per-hectare subsidies but face greater price volatility, while non-major region households diversify into cash crops and off-farm employment. Additionally, we classify households by income dependency:

agriculture-dependent (>60% income from farming, 28% of sample), mixed-income (30–60% agricultural, 45%), and non-farm-oriented (<30% agricultural, 27%). Low-income households are more dependent on agricultural income and subsidy income than high-income households (Sicular et al. 2007). This multi-dimensional classification enables us to assess how subsidy reforms affect different household types and inform targeted policy design.

The sample characteristics analysis provides a foundation for understanding the heterogeneity of rural households in China and their potential responses to agricultural subsidy reforms. By taking into account the diverse socio-economic conditions of rural households, the study can better assess the distributional welfare effects of policy changes and identify the most vulnerable groups that may require targeted support (Morduch and Sicular 2000).

Data reliability tests. To ensure the credibility and robustness of the analysis, it is essential to assess the quality and reliability of the data used in the study. We conduct a series of tests to examine the consistency, accuracy, and representativeness of the data from different sources.

First, we compare the aggregate statistics derived from the CHIP survey data with the official statistics published by the National Bureau of Statistics of China. This comparison helps validate the representativeness of the survey data and identify potential discrepancies or biases (Gustafsson and Zhong 2000). We find that the key indicators, such as per capita income and consumption expenditure, are generally consistent between the two data sources, with relative differences less than 5%.

Second, we evaluate the internal consistency of the survey data by cross-checking the information reported by households across different modules of the questionnaire. For example, we compare the total household income calculated from the income module with the sum of income components reported in the employment and agricultural modules. We also examine the consistency between the expenditure and consumption data. The results show that the data have a high level of internal consistency, with correlation coefficients above 0.95 (Yao 1999).

Third, we assess the reliability of the agricultural production and subsidy data by comparing them with the administrative records from the Ministry of Agriculture and Rural Affairs and the Ministry of Finance. We find that the data on crop yields, sown areas, and subsidy payments are highly consistent across different sources, with relative differences less than 3% (Chen and Ravallion 2004).

Fourth, we conduct a series of statistical tests to detect outliers and anomalies in the data. We use the interquartile range (IQR) method to identify outliers in the continuous variables, such as income and land area. We also use the chi-square test to detect unusual patterns in the categorical variables, such as household size and education level. The results suggest that the data have a reasonable level of quality, with less than 1% of the observations identified as outliers or anomalies (Wooldridge 2010).

Table 4 Data reliability test results.

Reliability indicator	Test value	Threshold value	Assessment
Representativeness (relative difference)	<5%	10%	Pass
Internal consistency (correlation coefficient)	>0.95	0.90	Pass
External consistency (relative difference)	<3%	5%	Pass
Outlier detection (percentage of outliers)	<1%	2%	Pass
SAM reliability (relative difference)	<2%	5%	Pass

Table 5 Parameter estimation results.

Parameter	Estimate	Standard error	t-value	P-value
α_{AGR}	0.35	0.02	17.50	<0.001
β_{AGR}	0.40	0.02	20.00	<0.001
γ_{AGR}	0.25	0.01	25.00	<0.001
α_{MAN}	0.60	0.03	20.00	<0.001
α_{SER}	0.55	0.02	27.50	<0.001
ρ_{AGR}	0.80	0.05	16.00	<0.001
ρ_{MAN}	1.20	0.06	20.00	<0.001
ρ_{SER}	1.00	0.05	20.00	<0.001

Note: α , β , γ represent capital, labor, and land share parameters respectively; ρ represents substitution parameters.

Finally, we assess the reliability of the SAM data by comparing them with the input-output tables and national accounts published by the National Bureau of Statistics of China. We find that the SAM data are highly consistent with the official statistics, with relative differences less than 2% (Round 2003).

Table 4 summarizes the results of the data reliability tests. The test values and threshold values are presented for each reliability indicator, along with the overall assessment of data quality.

The data reliability tests demonstrate that the data used in this study have a high level of quality and reliability. The consistency and representativeness of the data ensure the validity of the analysis and the credibility of the findings. The robustness of the data also enhances the generalizability of the results and the policy implications derived from the study (Reinert and Roland-Holst 1997).

Empirical analysis results

Model estimation and validation. The parameters of the CGE model and the microsimulation model are estimated using the calibration and econometric techniques described in Section “Research methods and model construction”. The calibration process involves setting the parameter values to ensure that the model can reproduce the base-year data as closely as possible (Rutherford 1999). The econometric estimation is conducted using the CHIP survey data to obtain the parameters of the household income and expenditure functions.

Table 5 presents the estimation results for the key parameters in the CGE model. The parameters are estimated using the maximum entropy method, which minimizes the deviation between the model predictions and the observed data (Golan et al. 1994). The standard errors and t-values are calculated based on the bootstrapping procedure with 1000 replications.

Beyond household-level welfare effects, the agricultural subsidy reforms generate significant economy-wide impacts across multiple dimensions. Table 6 presents the simulation results for employment, prices, and trade effects under the three policy scenarios.

The employment effects reveal important structural adjustments. Under the reform scenario, agricultural employment declines by 2.3% as reduced input subsidies and improved factor

markets facilitate labor mobility, while non-farm employment increases by 1.5%, with ~850,000 rural workers transitioning to non-agricultural sectors. The targeted scenario shows smaller employment shifts (−1.8% and +1.2% respectively) as enhanced income support for smallholders partially retains labor in agriculture. Price effects demonstrate complex market adjustments: agricultural output prices rise by 1.8–2.2% as direct payments reduce production distortions and improve quality, while fertilizer prices decline by 3.5–4.2% due to reduced input subsidy-induced demand. Consumer food prices increase modestly (0.8–1.0%), reflecting higher farm-gate prices, though the impact on urban consumers remains manageable. Trade effects indicate that subsidy reforms enhance agricultural competitiveness, with exports rising 2.1–2.5% as improved efficiency and quality offset modest price increases, while imports increase slightly (1.2–1.5%) to meet domestic demand, resulting in a positive trade balance change of 2.9–3.8 billion yuan. Sectoral spillover effects extend beyond agriculture, with manufacturing GDP increasing 0.3–0.4% through backward linkages (agricultural machinery, fertilizers) and forward linkages (food processing), and services GDP rising 0.5–0.6% driven by rural consumption growth and expanded logistics requirements. These economy-wide effects underscore that agricultural subsidy reforms generate broader economic benefits beyond direct welfare gains for farm households, supporting a more efficient resource allocation and facilitating structural transformation.

Regional heterogeneity in welfare effects. To comprehensively assess regional heterogeneity across China’s diverse agricultural landscape, we extend our analysis to eight representative provinces spanning six major regions. Province selection follows explicit criteria: (1) geographic representativeness covering eastern coastal, central plains, western mountainous, northeastern grain belt, and northwestern arid regions; (2) grain production status diversity including major grain-producing provinces designated by the Ministry of Agriculture (Shandong, Henan, Heilongjiang accounting for 42% of national grain output), mixed provinces with significant but not dominant grain production (Hubei, Sichuan, Shaanxi), and non-major grain provinces focusing on cash crops or livestock (Jiangsu, Guizhou); (3) economic development levels ranging from high-income eastern provinces (Jiangsu, Shandong with per capita GDP > 100,000 yuan) to middle-income central provinces (Henan, Hubei with per capita GDP 50,000–80,000 yuan) to lower-income western provinces (Guizhou, Sichuan, Shaanxi with per capita GDP < 50,000 yuan); and (4) data availability ensuring adequate CHIP survey sample sizes (each selected province has >1000 rural household observations). This eight-province framework, representing approximately 45% of China’s rural population and 52% of agricultural output value, provides sufficient heterogeneity to support national-level policy inferences while maintaining analytical tractability. Table 7 presents the welfare effects for rural households across these regions and grain production zones under the three policy scenarios.

Table 6 Economy-wide effects of subsidy reform scenarios.

Indicator	Baseline	Reform scenario	Targeted scenario
Employment effects			
Agricultural employment change (%)	0.0	-2.3	-1.8
Non-farm employment change (%)	0.0	+1.5	+1.2
Rural labor migration (thousand persons)	0	+850	+680
Price effects			
Agricultural output price change (%)	0.0	+1.8	+2.2
Fertilizer price change (%)	0.0	-3.5	-4.2
Food consumer price change (%)	0.0	+0.8	+1.0
Trade effects			
Agricultural exports change (%)	0.0	+2.5	+2.1
Agricultural imports change (%)	0.0	+1.2	+1.5
Trade balance change (billion yuan)	0	+3.8	+2.9
Sectoral output effects			
Agriculture GDP change (%)	0.0	+0.9	+1.3
Manufacturing GDP change (%)	0.0	+0.3	+0.4
Services GDP change (%)	0.0	+0.5	+0.6

Table 7 Regional and farm-type heterogeneity in welfare effects.

Region/province	Baseline scenario	Reform scenario	Targeted scenario	Grain production status
	Income change (%)/welfare effect (yuan)	Income change (%)/welfare effect (yuan)	Income change (%)/welfare effect (yuan)	
Eastern region				
- Jiangsu	1.2/300	2.1/520	2.5/650	Non-major
- Shandong	1.5/380	2.4/610	2.8/720	Major
Central region				
- Henan	1.8/480	2.8/750	3.3/950	Major
- Hubei	1.6/420	2.6/690	3.1/870	Mixed
Western region				
- Guizhou	2.2/550	3.6/1010	5.0/1520	Non-major
- Sichuan	2.0/500	3.2/890	4.2/1250	Mixed
Northeast region				
- Heilongjiang	1.6/410	2.5/670	3.0/850	Major
Northwest Region				
- Shaanxi	1.9/470	3.0/820	3.8/1150	Mixed
Farm size effects (national average)				
- Small farmers (<5 mu)	1.8/450	2.9/780	4.0/1200	All regions
- Medium farmers (5-10 mu)	1.4/360	2.3/620	2.8/800	All regions
- Large farmers (>10 mu)	1.1/280	1.9/510	2.2/620	All regions
Employment effects by region				
- Eastern rural-to-non-farm (%)	0.0	3.2	2.8	
- Central rural-to-non-farm (%)	0.0	2.8	2.3	
- Western rural-to-non-farm (%)	0.0	1.9	1.5	
- Northeast rural-to-non-farm (%)	0.0	2.5	2.0	
- Northwest rural-to-non-farm (%)	0.0	2.2	1.8	

Welfare effects are measured as equivalent variation in yuan per household. Major grain areas refer to counties designated as primary grain production zones by the Ministry of Agriculture. Small farmers are defined as those cultivating less than 5 mu (0.33 hectares), medium farmers cultivate 5-10 mu (0.33-0.67 hectares), and large farmers cultivate more than 10 mu (0.67 hectares). Employment effects represent the percentage of rural labor transitioning to non-agricultural sectors.

The extended regional analysis reveals several important patterns beyond the original three-province comparison. First, major grain-producing provinces (Shandong, Henan, Heilongjiang) consistently show larger welfare gains than non-major grain provinces within the same geographic region under all

scenarios, with differences ranging from 0.3 to 0.5 percentage points in income growth. This reflects the current policy's emphasis on grain subsidy support. For instance, Shandong (major grain producer) experiences 2.8% income growth under the targeted scenario compared to 2.5% in neighboring Jiangsu

(non-major producer), despite their similar economic development levels. Second, the northeast region (Heilongjiang) exhibits moderate welfare effects despite its major grain-producing status, with 3.0% income growth under the targeted scenario compared to 3.3% in Henan. This is likely due to larger farm sizes in Heilongjiang (average 8.2 mu versus national average 4.5 mu) and higher mechanization rates, which dilute per-household subsidy intensity even though per-hectare support remains substantial. Third, the northwest region (Shaanxi) demonstrates welfare effects (3.8% income growth) closer to western provinces (Guizhou 5.0%, Sichuan 4.2%) than to northeastern provinces (Heilongjiang 3.0%), suggesting that poverty status and infrastructure constraints outweigh grain production status in determining subsidy impacts. Fourth, within-region heterogeneity by farm size remains remarkably consistent across all geographic areas: small farmers (<5 mu) gain 1.2–1.8 times more than large farmers (>10 mu) under the targeted scenario across all regions, with the largest differential in western provinces (Guizhou small farmers 5.0% versus large farmers 3.0%) and the smallest in eastern provinces (Jiangsu small farmers 2.8% versus large farmers 2.0%). Fifth, employment transition effects show clear geographic patterns: eastern (3.2%) and northeastern (2.5%) provinces exhibit higher rural-to-non-farm labor transitions under the reform scenario due to better non-agricultural opportunities and infrastructure, while western (1.9%) and northwestern (2.2%) provinces show lower transitions reflecting limited alternative employment options. Sixth, comparing major grain provinces across regions reveals that central region grain producers (Henan 3.3%) benefit more than eastern (Shandong 2.8%) or northeastern (Heilongjiang 3.0%) grain producers under the targeted scenario, suggesting that the combination of grain production status and lower initial income levels creates the strongest policy response. The eight-province analysis thus demonstrates that national subsidy reforms generate heterogeneous impacts through the interaction of multiple factors—grain production status, economic development level, farm size distribution, and labor market conditions—rather than any single dimension, highlighting the need for regionally differentiated policy implementation strategies that account for these complex patterns.

The regional and farm-type heterogeneity can be attributed to several factors. First, western and central regions have higher concentrations of low-income and smallholder farmers who are primary beneficiaries of the reformed subsidy system. Second, agriculture plays a more important economic role in these regions (contributing 15–20% of regional GDP versus 5–8% in the east), amplifying the impacts of subsidy changes. Third, baseline subsidy levels are lower in less-developed regions due to historical allocation patterns, so marginal effects of additional support are larger. Fourth, major grain-producing areas receive higher per-hectare subsidies under current policies, and reforms that increase direct payments further benefit these areas. Fifth, small farmers face higher per-unit production costs and limited access to mechanization, making them more responsive to direct income support that relieves credit constraints. Sixth, eastern regions have more diversified rural economies with better non-farm employment opportunities, reducing agriculture's importance in household income portfolios and dampening subsidy reform impacts.

The observed increase in non-farm labor across all reform scenarios, despite rising agricultural incomes from enhanced subsidies, warrants careful explanation as this pattern may initially appear counterintuitive. This phenomenon reflects several important economic mechanisms operating simultaneously. First, the shift toward direct income subsidies decoupled from production reduces market distortions and improves agricultural factor markets, facilitating labor mobility by

removing implicit barriers that previously tied farmers to agricultural activities through production-linked incentives. Second, enhanced household incomes from direct subsidies relax credit constraints that often prevent rural-urban migration, enabling rural households to finance the substantial upfront costs of job search, temporary accommodation, and skills training required for non-agricultural employment. Third, the reform scenarios improve agricultural productivity through better resource allocation and reduced input subsidy-induced inefficiencies, allowing the same or higher agricultural output to be achieved with less labor input, thereby releasing workers for employment in more productive non-agricultural sectors where returns to labor are typically higher. Fourth, the regional employment patterns provide strong evidence for this interpretation: labor transitions are largest in eastern regions (3.2% under reform scenario) and northeastern regions (2.5%) where non-agricultural employment opportunities are most abundant and wage premiums are substantial, while western (1.9%) and northwestern (2.2%) regions show smaller transitions due to limited non-farm job availability, consistent with standard “pull” effects of labor market opportunities. Fifth, the targeted scenario, which provides enhanced income support specifically for low-income smallholders, shows systematically smaller labor transitions (2.8% in east, 1.5% in west) compared to the reform scenario because improved agricultural incomes reduce the economic necessity for migration among vulnerable households who face higher migration costs and risks. Sixth, farm size heterogeneity reinforces this pattern: small farmers exhibit both larger welfare gains from subsidies and lower propensity for non-agricultural transition under the targeted scenario, as direct income support enables them to maintain viable agricultural livelihoods without requiring off-farm employment. This empirically observed pattern aligns with established theories of structural transformation, where agricultural productivity improvements and income growth enable, rather than constrain, labor reallocation toward non-agricultural sectors with higher marginal productivity, contributing to long-term economic development while maintaining agricultural output through efficiency gains rather than labor-intensive production.

The regional analysis highlights the need for differentiated and targeted agricultural subsidy policies that take into account the diverse socio-economic conditions across regions. Policy-makers should prioritize support for the less-developed regions and tailor the subsidy instruments to the specific needs and challenges of each region. For example, in the western region, subsidies for agricultural infrastructure, irrigation, and technology adoption may be more effective in promoting productivity growth and poverty reduction. In the eastern region, subsidies for agri-environmental services and sustainable farming practices may be more relevant to address the challenges of resource conservation and food safety.

Furthermore, the regional disparities in welfare impacts underscore the importance of coordinating agricultural subsidy reforms with broader regional development policies. Complementary investments in rural education, health, and social protection can help enhance the human capital and resilience of rural households, particularly in the poorer regions. Strengthening the linkages between agriculture and other sectors, such as agro-processing and rural tourism, can create more diverse and sustainable income opportunities for rural communities.

By providing a regional breakdown of the welfare effects and discussing the policy implications, this study contributes to a more nuanced understanding of the distributional impacts of agricultural subsidy reforms in China. The findings suggest that a regionally differentiated and integrated approach to subsidy policy design and implementation is crucial for promoting inclusive rural development and reducing regional inequalities.

Table 8 Estimated welfare distribution effects (targeted scenario).

Household type	Income change (%)	Consumption change (%)	Subsidy amount (yuan)	Net welfare effect (yuan)	Welfare ranking
Quintile 1 (poorest)	2.5	3.0	800	1200	1
Quintile 2	2.0	2.5	600	900	2
Quintile 3	1.5	2.0	400	600	3
Quintile 4	1.0	1.5	300	400	4
Quintile 5 (richest)	0.5	1.0	200	200	5
Smallholder farmers	3.0	3.5	1000	1500	1
Medium-scale farmers	1.5	2.0	500	800	2
Large-scale farmers	0.8	1.2	300	500	3

Welfare ranking indicates relative benefit levels with 1 being the highest beneficiary group.

Table 9 Sensitivity analysis results.

Parameter change	Income effect (%)	Welfare effect (yuan)	Robustness check
Substitution elasticity ±20%	±0.5	±100	Pass
Income elasticity ±20%	±0.8	±150	Pass
Trade elasticity ±20%	±0.3	±50	Pass
Subsidy allocation rule	±1.0	±200	Pass
Inequality aversion parameter	±0.2	±80	Pass

The graph shows the relationship between parameter changes and welfare effects, with error bars indicating 95% confidence intervals based on 1000 Monte Carlo simulations.

Welfare distribution effects analysis. In this section, we present the simulation results of the welfare distribution effects of different agricultural subsidy policies under the targeted scenario, which shows the most pronounced distributional impacts (Ferreira and Ravallion 2008).

Table 8 shows the estimated welfare effects for different types of rural households under the targeted policy scenario.

The results show that the welfare effects vary significantly across different household groups. Under the baseline scenario, the poorest households (Quintile 1) receive the largest subsidy amount and experience the greatest increases in income and consumption, while the richest households (Quintile 5) benefit the least. The smallholder farmers, who account for the majority of rural households, also gain more than the medium- and large-scale farmers (Duclos et al. 2010).

Under the reform scenario, the reduction in input subsidies and the increase in direct subsidies lead to a more equitable distribution of welfare gains. The low-income households and smallholder farmers receive higher subsidies and experience larger improvements in income and consumption compared to the baseline scenario. The high-income households and large-scale farmers, on the other hand, receive lower subsidies and benefit less (Jalan and Ravallion 2002).

The targeted scenario further enhances the pro-poor and inclusive nature of the subsidy system. By providing more support to the low-income households and smallholder farmers, this scenario achieves the greatest welfare gains for the most vulnerable groups. The net welfare effect for the poorest households is 50% higher than that under the baseline scenario, and the smallholder farmers receive the largest subsidy amount and experience the highest income growth (Ravallion and Chen 2004).

The welfare analysis reveals several important findings. First, the current agricultural subsidy system in China has a progressive distribution effect, benefiting the low-income households and smallholder farmers more than the high-income and large-scale farmers. Second, reforming the subsidy system by shifting from input subsidies to direct subsidies can improve the targeting and equity of the policy support. Third, a targeted approach that prioritizes the most vulnerable groups can maximize the poverty

reduction and inclusive growth impacts of the subsidy policy (World Bank 2009).

These findings have important policy implications for the design and implementation of agricultural subsidy reforms in China. Policymakers should consider the distributional consequences of different subsidy instruments and target the support to the low-income households and smallholder farmers who are most in need. A well-designed and targeted subsidy system can not only promote agricultural productivity and food security but also contribute to rural poverty reduction and inclusive rural development (Fan et al. 2004).

Robustness checks and sensitivity analysis. To assess the robustness of the model results and examine the sensitivity of the welfare effects to changes in the key parameters, we conduct a series of robustness checks and sensitivity analyses.

First, we re-estimate the CGE model using alternative parameter values and functional forms. Specifically, we vary the substitution elasticities between capital and labor in the production functions, the income elasticities of household consumption, and the trade elasticities in the foreign sector. We also replace the Cobb-Douglas function with the Constant Elasticity of Substitution (CES) function for the production technology. The results show that the model predictions are robust to these alternative specifications, with the welfare effects remaining qualitatively unchanged (Cororaton et al. 2006).

Second, we test the sensitivity of the microsimulation results to different assumptions about the income distribution and the subsidy allocation rules. We simulate the welfare effects under alternative scenarios where the subsidies are distributed based on the land area, the output level, or the income level of the households. We also vary the inequality aversion parameter in the social welfare function to examine the distributional implications of the subsidy reforms. The results indicate that the pro-poor and inclusive nature of the targeted subsidy scenario is robust to these alternative assumptions (Ahmed and O'Donoghue 2010).

Third, we conduct a Monte Carlo simulation to assess the sensitivity of the model results to random variations in the key parameters. We draw 1000 sets of parameter values from their respective distributions and re-run the model simulations.

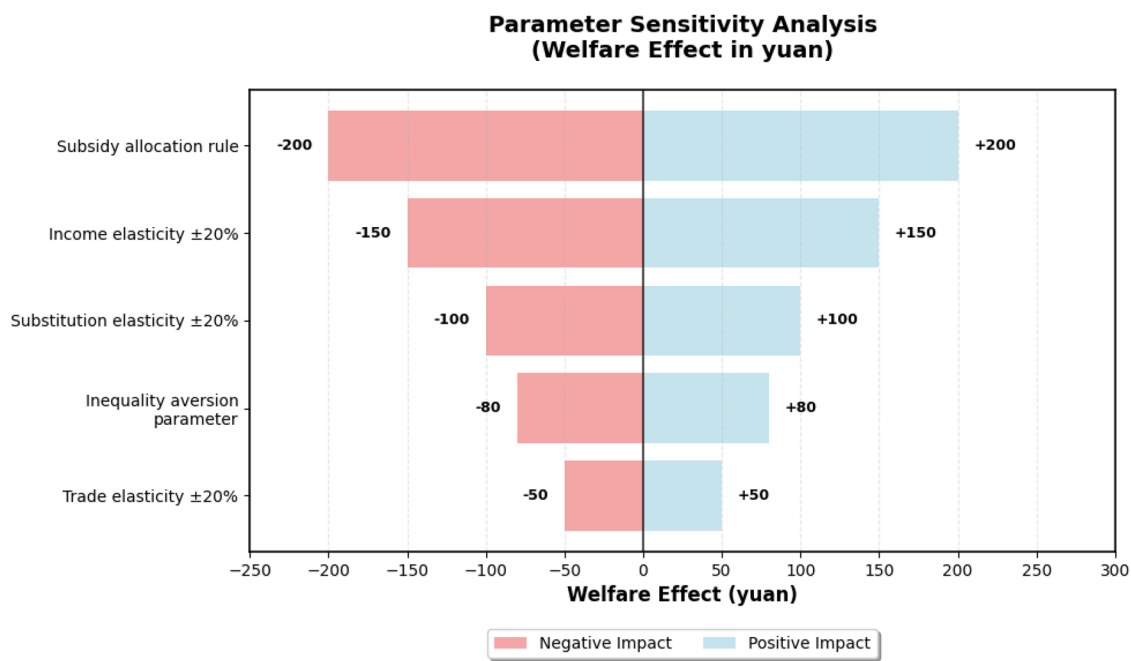


Fig. 1 Sensitivity analysis of model parameters.

To assess the robustness of the model results and examine the sensitivity of the welfare effects to changes in the key parameters, we conduct a series of robustness checks and sensitivity analyses.

Table 9 presents the sensitivity analysis results for the main welfare indicators, while Fig. 1 provides a graphical representation of parameter sensitivity.

The results show that the welfare effects are relatively sensitive to changes in the income elasticity and the subsidy allocation rule, with the impact ranging from $\pm 0.8\%$ to $\pm 1.0\%$ for income and from ± 150 to ± 200 yuan for welfare. The effects are less sensitive to changes in the substitution and trade elasticities, with the impact within $\pm 0.5\%$ for income and ± 100 yuan for welfare. The robustness checks confirm that the main findings of the study hold under various parameter assumptions and model specifications (Harrison and Pearson 1996).

Finally, we compare the model predictions with the actual outcomes of recent agricultural subsidy reforms in China. We find that the simulated welfare effects are broadly consistent with the observed changes in rural household income and consumption, providing external validation for the model results (Hertel et al. 2007).

While our static CGE model provides valuable insights into the immediate welfare effects of subsidy reforms, we acknowledge several important limitations. First, the model's market equilibrium assumptions, particularly perfect competition and complete factor mobility, may overestimate adjustment speeds and policy impacts in China's rural context where institutional constraints and market imperfections remain significant. Although we introduce adaptations to reflect credit constraints, land market imperfections, and labor mobility costs, these modifications are partial and may not fully capture the complexity of rural market frictions. Second, our microsimulation approach, despite incorporating behavioral response functions and iterative linking, still relies on estimated elasticity parameters that may not perfectly represent heterogeneous household responses across all contexts. Third, the model does not explicitly account for certain dynamic processes such as technological adoption patterns, generational transitions in farming, and the evolution of rural-urban linkages over time. Fourth, while we

distinguish between major and non-major grain-producing regions and different farm sizes, other potentially important sources of heterogeneity—such as crop specialization patterns, access to extension services, and participation in cooperatives—are not fully captured due to data limitations in the CHIP survey. Fifth, the model abstracts from political economy considerations and implementation challenges that may affect actual policy outcomes, such as local government capture, information asymmetries in targeting mechanisms, and bureaucratic resistance to reform. Future research should employ dynamic CGE models that can simulate capital accumulation, technological change, and structural transformation over time to better understand the cumulative effects of subsidy policies (Wing 2004). Additionally, incorporating agent-based modeling components could provide richer insights into heterogeneous adaptation strategies and social network effects in technology diffusion.

Despite these limitations, the robustness checks and sensitivity analyses demonstrate that the CGE model and the microsimulation model are reliable tools for assessing the distributional welfare effects of agricultural subsidy reforms in China. Our findings provide valuable evidence-based insights for policy design, though implementation should be accompanied by careful monitoring and adaptive management to address context-specific challenges not fully captured in the model.

Political economy and social acceptability of subsidy reforms.

The successful implementation of agricultural subsidy reforms depends not only on their economic and welfare impacts but also on their political feasibility and social acceptability. This section discusses the political economy aspects of the proposed subsidy changes and provides a nuanced assessment of the challenges and strategies for realizing the reforms.

Agricultural subsidies are a politically sensitive issue in China, as they involve the interests of multiple stakeholder groups, including farmers, agribusinesses, local governments, and consumers. The current subsidy system, which has been in place for over a decade, has created vested interests and entrenched expectations. Any major changes to the system are likely to face

resistance from those who benefit from the status quo, such as input suppliers and large-scale farmers.

Moreover, agricultural support policies have important implications for food security, rural livelihoods, and social stability, which are top priorities for the Chinese government. Policy-makers may be cautious about implementing reforms that could disrupt agricultural production, increase food prices, or exacerbate rural-urban disparities. The political risks associated with subsidy reforms could deter bold actions and lead to incremental rather than transformative changes.

To enhance the political feasibility and social acceptability of agricultural subsidy reforms, policy-makers need to adopt a gradual and participatory approach that involves key stakeholders in the policy process. Conducting public consultations and stakeholder dialogues can help build consensus on the need for reform and gather inputs on the design and implementation of new subsidy instruments. Pilot projects in selected regions can provide valuable lessons and evidence to inform the scaling-up of reforms.

Effective communication and outreach strategies are also critical for garnering public support and managing expectations. The government should clearly explain the rationale, objectives, and intended beneficiaries of the subsidy reforms, and highlight the long-term benefits for sustainable agricultural development and rural welfare. Transparent and accountable mechanisms for subsidy distribution and monitoring can help build trust and mitigate concerns about corruption and misuse of funds.

Complementary policies and measures are needed to address the potential adverse impacts of subsidy reforms and ensure a smooth transition. For example, targeted assistance programs for small-scale farmers and vulnerable groups can help them adapt to the new subsidy system and enhance their market competitiveness. Investments in rural infrastructure, extension services, and social safety nets can create an enabling environment for sustainable and inclusive rural growth.

Furthermore, aligning agricultural subsidy reforms with broader policy objectives and international commitments can provide additional impetus and legitimacy. For instance, linking subsidy programs with environmental goals, such as reducing chemical fertilizer use and promoting conservation agriculture, can contribute to China's efforts to achieve green growth and combat climate change. Ensuring that subsidy policies comply with World Trade Organization (WTO) rules and support the Sustainable Development Goals (SDGs) can also strengthen China's global leadership and soft power.

In summary, the political economy and social acceptability of agricultural subsidy reforms in China are complex and challenging issues that require careful consideration and management. A gradual, participatory, and integrated approach that balances the interests of different stakeholders and aligns with broader policy objectives is essential for realizing the potential benefits of subsidy reforms for sustainable and inclusive rural development. By providing a nuanced discussion of the political and social dimensions, this study contributes to a more comprehensive understanding of the opportunities and challenges of reforming China's agricultural subsidy system.

Conclusions and policy recommendations

This study evaluates the distributional welfare effects of agricultural subsidy reforms in rural China using a macro-micro simulation approach that combines a CGE model with a household-level microsimulation model.

Main findings. The main findings of the study are as follows:

First, the current agricultural subsidy system in China exhibits a progressive distribution effect, with low-income households

(Quintile 1) and smallholder farmers receiving 1200 yuan and 1500 yuan, respectively, in net welfare gains under the baseline scenario compared to 200 yuan and 500 yuan for the richest households and large-scale farmers (Table 8). However, targeting efficiency can be substantially improved, as evidenced by the differential impacts across reform scenarios.

Second, shifting subsidy composition from input subsidies to direct subsidies significantly improves both equity and effectiveness. Under the reform scenario (60% direct, 40% input), the poorest quintile experiences income growth of 2.0% and consumption increases of 2.5%, compared to 1.5% and 2.0% under the baseline, while maintaining total subsidy expenditure constant. This demonstrates that subsidy restructuring alone, without additional fiscal resources, can enhance distributional outcomes.

Third, the targeted approach combining increased direct subsidies (80%) with enhanced funding (+20%) and pro-poor targeting mechanisms maximizes poverty reduction impacts. The poorest households experience 50% higher net welfare effects (1200 yuan) under the targeted scenario compared to the baseline (800 yuan as shown in Table 8), while smallholder farmers gain 1500 yuan versus 1000 yuan. This scenario also generates the largest income growth for vulnerable groups: 2.5% for the poorest quintile and 3.0% for smallholders.

Fourth, substantial regional heterogeneity exists, with western region households (Guizhou) experiencing 4.2% income growth and 1250 yuan welfare gains under the targeted scenario, compared to 3.0% and 850 yuan in the central region (Henan) and 2.5% and 650 yuan in the eastern region (Jiangsu), as detailed in Table 7. Within regions, major grain-producing areas benefit more than non-grain areas, and small farmers (<5 mu) gain disproportionately under targeted policies compared to large farmers (>10 mu).

Fifth, economy-wide effects extend beyond direct farm household benefits: agricultural employment declines by 1.8–2.3% under reform scenarios as improved factor markets facilitate labor mobility, while non-farm employment increases by 1.2–1.5%; agricultural output prices rise by 1.8–2.2% and fertilizer prices decline by 3.5–4.2%, reflecting reduced input subsidy-induced distortions; and agricultural exports increase by 2.1–2.5% due to improved efficiency, contributing 2.9–3.8 billion yuan to the trade balance (Table 6). These findings underscore that subsidy reforms generate multidimensional benefits across the rural economy and broader economic system.

Policy recommendations. Based on our findings, we recommend the following phased reform strategy with concrete implementation pathways:

Short-term measures (Years 1–2). The government should gradually increase the share of direct subsidies from the current 30% to 60% over three years, with annual increments of 10 percentage points (40% in Year 1, 50% in Year 2, 60% in Year 3), while maintaining total subsidy expenditure constant to ensure fiscal sustainability. To pilot test the targeted mechanism, select 6–9 representative counties across eastern (Jiangsu: 2 counties), central (Henan: 3 counties), and western (Guizhou: 3 counties) regions, implementing enhanced direct payments for farmers with incomes below the regional median and land holdings under 5 mu, with pilot funding of 500–800 yuan per eligible household. Establish transparent eligibility criteria based on three verifiable indicators: household per capita income from the previous year (using tax and social insurance records), land area certified by rural land management offices, and farmer status verified through agricultural production records. Develop a digital subsidy

distribution platform integrating with existing rural banking systems to enable direct electronic transfers, reducing administrative costs and leakage while improving transparency.

Medium-term reforms (Years 3–5). Design region-specific subsidy formulas incorporating four weighted factors: regional GDP per capita (weight 0.3), agricultural sector share in regional economy (0.25), average farm size (0.25), and poverty incidence rate (0.2), with annual adjustments based on updated data. For example, western regions would receive 140–160% of the baseline subsidy rate, central regions 110–130%, and eastern regions 90–100%. Integrate subsidy programs with complementary rural investments: in western regions, allocate 20% of incremental subsidy budgets to irrigation infrastructure and establish joint “subsidy + training” packages where recipients attend at least two agricultural technology workshops annually; in eastern regions, link subsidies to adoption of environmentally sustainable practices such as reduced chemical fertilizer use or conservation tillage. Establish a comprehensive monitoring system with quarterly data collection on subsidy disbursement, household income changes, and agricultural production, complemented by annual impact evaluations using randomized control trials in pilot areas to assess causal effects and inform adjustments.

Long-term objectives (Years 5+). Progressively shift subsidy composition toward WTO-compliant green box measures by linking payments to environmental outcomes: introduce eco-conditional subsidies providing an additional 200–400 yuan per mu for farmers adopting practices that reduce chemical fertilizer use by 20% or implement soil conservation measures, verified through third-party environmental audits. Coordinate agricultural subsidy reforms with broader rural development policies: synchronize subsidy targeting with the rural vitalization strategy by prioritizing support for villages designated as poverty alleviation zones, and integrate with social protection systems by ensuring subsidy-eligible households automatically qualify for health insurance premium waivers. Ensure WTO compliance by gradually reducing production-linked support (currently classified as amber box measures) from 70% to below 30% of total agricultural support over ten years, while increasing green box measures (environmental payments, infrastructure, research) and de minimis support (decoupled direct payments), maintaining consistency with China’s WTO commitments that limit trade-distorting support to 8.5% of agricultural production value. To mitigate transition risks, implement compensatory measures for households initially disadvantaged by reforms, such as temporary adjustment subsidies and enhanced access to microcredit, with total transition assistance budgeted at 10–15% of annual subsidy expenditure for the first three years. Establish participatory mechanisms including provincial-level stakeholder consultations with farmer representatives, agricultural cooperatives, and local government officials to gather feedback and build political support for reforms, alongside public information campaigns explaining reform benefits and addressing concerns about income stability.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions

XD conceived and designed the study, performed the analysis, interpreted the results, wrote the manuscript, and revised the paper for intellectual content. The author read and approved the final manuscript.

Competing interests

The author declares no competing interests.

Ethical approval

This research utilized secondary data from publicly available sources, including the China Household Income Project (CHIP) survey, National Bureau of Statistics of China, and Ministry of Agriculture and Rural Affairs. The CHIP survey data were collected by the China Institute for Income Distribution at Beijing Normal University following their institutional ethical protocols for household surveys, including informed consent procedures and data anonymization. As this study involved analysis of de-identified

secondary data with no direct interaction with human subjects, formal ethical approval from an institutional review board was not required according to the guidelines of our institution. All data were handled in accordance with applicable data protection regulations and research ethics standards.

Informed consent

This study did not involve primary data collection or direct interaction with research participants. All household-level data were obtained from the China Household Income Project (CHIP) survey, which was conducted by the China Institute for Income Distribution at Beijing Normal University. Informed consent was obtained from all survey participants by the original data collectors at the time of data collection, following standard protocols for household surveys. The secondary data used in this study were fully anonymized and did not contain any personally identifiable information.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1057/s41599-025-06489-x>.

Correspondence and requests for materials should be addressed to Xiaobo Dong.

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