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The overall spatial spillover effects of local agricultural policy: A study on China's corn stockpiling policy based on Adaptive Expectation Theory and Spatial Durbin Model

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Abstract: In 2007, the Chinese government introduced a temporary corn storage policy targeting four regions: Heilongjiang, Jilin, Liaoning and Inner Mongolia. This policy aimed at stabilising grain markets and ensured farmers' income by providing price support for corn. Its implementation significantly impacted corn prices and the regional distribution of corn cultivation, offering a valuable case for analysing the economic outcomes of China's agricultural policies. This study adopts the adaptive expectations hypothesis to explore the policy's effects, focusing on its influence on farmers' price expectations (mean) and price volatility (variance). Using a Spatial Durbin Model (SDM), we empirically investigate the policy's dynamic regional impacts on corn planting areas. The results show that the temporary corn storage policy significantly increased corn planting areas in the targeted regions, while simultaneously reducing planting areas in non-targeted regions due to negative spatial spillover effects. At the national level, the policy had no statistically significant impact on total corn planting areas, indicating that abolishing the policy alone is unlikely to rationalise or optimise the agricultural planting structure.

Keywords: agricultural price; corn acreage; spatial econometrics; support policy

Agricultural production is shaped by both natural and socio-economic factors, with the natural environment playing a critical role in determining the spatial distribution of crops. For instance, in China, climatic differences between the south and north dictate the cultivation patterns of rice and wheat. While the natural environment is relatively stable in the short term, the spatial distribution of crops evolves continuously due to other factors, such as agricultural policies. In this paper, we focus on the impact of agricultural price support policies on the spatial distribution of corn cultivation, with a particular emphasis on China's unique temporary corn stockpiling policy.

Unlike the comprehensive implementation of agricultural price support policies in many countries, China's corn price support policy was region-specific, implemented only in four northern provinces: Heilongjiang, Jilin, Liaoning and Inner Mongolia. This unique feature provides an exceptional empirical setting for studying the spatial spillover effects of economic policies. The regional variability of this policy enables researchers to analyse not only the local effects of its implementation

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but also the transmission of these effects to non-policy regions through market mechanisms. Furthermore, China's unified domestic market allows for the isolation of spatial spillover effects without interference from international trade policies, making it a valuable case for global studies on agricultural policy impacts.

Since 1980, the spatial distribution of corn cultivation in China has undergone significant changes, with increasing agglomeration and a shift in production focus towards the north (Deng et al. 2013; Li et al. 2016; Xu et al. 2017). While climate change is a major contributing factor, the influence of socio-economic factors such as urbanisation, non-agricultural employment, transportation, livestock development, and comparative crop profitability should not be overlooked (Chen et al. 2015). Among these, agricultural policies, particularly the temporary corn stockpiling policy implemented in 2008 and its subsequent cancellation in 2016, have played a critical role in shape corn cultivation patterns.

Existing studies have examined the broader effects of grain price changes on planting decisions (Jia el al. 2017), but few have isolated the specific impact of price support policies on corn acreage. Moreover, most studies on this policy focus solely on those for implementation provinces (Fan et al. 2016), neglecting potential spatial spillover effects. Given that corn is a bulk commodity suitable for long-distance transportation, regional price differences and transportation costs, rather than regional market segmentation, primarily influence its spatial distribution (Clary et al. 1986; Branco et al. 2021). The temporary corn stockpiling policy created regional price disparities, which likely affected corn planting decisions in non-policy regions via market mechanisms.

Building on the agricultural supply response model proposed by Nerlove (1958), which highlights the role of farmers' price expectations in planting decisions, this paper examines how China's temporary corn stockpiling policy influenced farmers' price expectations and their subsequent planting decisions. Previous studies oversimplified price expectations, using only the prior year's corn price as a proxy (Xu and Zhang 2021), and failed to account for the stabilising effect of price support policies on farmers' expectations. By incorporating the effects of price expectations and volatility induced by the policy, this study provides a more nuanced understanding of farmers' decision-making processes.

This paper makes contributions in the following aspects. First, previous studies on similar agricultural supporting policies have typically focused on entire countries as the unit of analysis. However, due to the influence of trade policies on agricultural product trade between countries, it is challenging to effectively identify the spatial spillover effects of these policies. China's temporary corn storage policy is a regional policy implemented within a unified domestic market, where both the policy-implementing regions and other regions operate without trade policy interference. This unique setting enables this study to better isolate and identify the spatial spillover effects of regional agricultural supporting policies. Second, unlike existing studies that directly assess the spatial effects of the temporary corn storage policy, this paper establishes a pathway from the policy to farmers' price expectations for corn and then to their planting decisions. We first analyse how the temporary corn storage policy affects farmers' price expectations for corn and subsequently use simulation analysis to measure how changes in expected prices and their volatility induced by the policy influence planting decisions in both local and neighbouring regions. Finally, this study finds that the temporary corn storage policy impacts corn planting in neighbouring regions primarily through its effects on farmers' expectations of price volatility. This mechanism, which plays a central role in the spatial effects of the policy, has not been addressed in existing research.

Although the temporary corn stockpiling policy has been discontinued, its impacts remain a valuable area of exploration. This analysis not only provides a reflection on the policy's effectiveness but also offers insights for evaluating similar price support reforms for other agricultural products, such as wheat. By situating this study within the broader context of agricultural policy research, we aim to contribute both empirical evidence and theoretical insights to the international literature on spatial economics and agricultural policy impacts.

Spatio-temporal corn acreage change and corn stockpiling policy

Spatio-temporal corn acreage change. Between 1984 and 2014, China witnessed continuous and steady growth in both the acreage of land dedicated to corn cultivation and the total corn yield. In 1984, the country's corn planting area stood at 18.537 million ha, resulting in a total output of approximately 74 million tons. By 2014, the planted area had expanded significantly to 37.123 million ha, accompanied by a marked increase in output to 216 million tons. This sustained

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growth stemmed from an interplay of various complex factors, with a pivotal contribution from adjustments in the agricultural structure.

From the perspective of spatial distribution, between 1984 and 2014, China's corn planting areas underwent significant changes, mainly characterised by the gradual reduction of planting areas in the southern regions, in stark contrast to the continuous expansion in the northern regions. Among these, the Northeast region, with its advantages in land reserves, fertile black soil resources, and suitable climate and geographical conditions for large-scale mechanised agricultural production, gradually became prominent and established its important position as a major corn-producing area in China. Data shows that the corn planting area in the Northeast region steadily increased from about 27% of the national total in 1984 to about 43% in 2014. This significant increase is not only attributed to the superiority of natural resources but also reflects the continuous inclination of national agricultural policies, especially grain policies, towards this region. In North China, encompassing Beijing, Tianjin, Hebei and Inner Mongolia, advanced irrigation systems and high-quality farmland provide favourable conditions for corn cultivation. Although the areas dedicated to corn planting in Beijing and Tianjin have declined, North China's proportion of the national corn planting area increased from 14% in 1984 to 19% by 2014.

Conversely, the corn planting areas in South and Southwest China have exhibited a declining trend. Data analysis indicates that the proportion of these regions' corn cultivation areas, relative to the national total, decreased from 20% in 1984 to 12% by 2014. Unlike the vast land availability typical of northern China, the South and Southwest regions generally face constraints in land resources. Additionally, with the gradual evolution of a more market-oriented agricultural structure, local regions have increasingly redirected agricultural resources toward rice cultivation and cash crops, which offer higher economic returns and greater competitiveness. As a result, farmland in these southern regions is increasingly allocated to more profitable crops, while corn has experienced a gradual reduction in cultivation, reflecting a clear trend of 'withdrawal.'

Corn stockpiling policy. In response to the significant decrease in international grain prices in 2008, China's corn and soybean markets faced substantial downward pricing pressures, threatening agricultural production. To mitigate these effects, the Chinese government initiated a temporary storage policy for various crops, including soybeans, corn, cotton and rapeseed, with the policy specifically concerning corn being applied in Heilongjiang, Jilin, Liaoning and Inner Mongolia. This policy entailed setting predetermined prices and quantities for temporary storage, based on the market conditions, and was executed by state-owned grain enterprises purchasing at these set prices. During the implementation of the policy, the Chinese government continuously increased the purchase price of corn, from USD 214 per ton in 2008 to USD 354 per ton in 2016. At the same time, the government allowed more and more state-owned enterprises to participate in corn purchases, which further drove up the purchase price and led farmers to form expectations of rising corn prices.

This intervention led to discrepancies between domestic and international food prices, an imbalance in food supply and demand, and simultaneous increases in grain stocks, production, and imports. In light of these challenges, the state commenced reform of the corn collection and storage system in 2016, ceasing direct price interventions. Consequently, producers began selling corn at market prices, supported by a state-established subsidy system based on their planting area. This shift in policy altered farmers' expectations regarding future prices, thereby mitigating the price volatility associated with corn cultivation.

In the preceding section, we analysed the spatial variations in corn production, attributing one of the key factors to the introduction of the temporary corn storage policy.

The impact of the corn temporary storage policy on corn planting can be seen in Figure 1. In this figure, we compare the growth rates of corn planting areas in the policy implementation regions (four provinces/regions) and neighbouring provinces (including Hebei, Shanxi, Shaanxi, Gansu and Ningxia). It can be observed that before 2008, there was a clear common trend in the growth rates of corn planting areas in both regions. However, after 2008, there was no apparent common trend. This can also be confirmed through a simple cointegration test: before 2008, the growth rates of corn planting areas in both regions were cointegrated and statistically significant at the 1% level, but after 2008, there was no cointegration relationship. This indicates that the linkage between the four provinces/regions and neighbouring provinces in terms of corn planting area was broken after the implementation of the corn temporary storage policy. This to some extent reflects the effectiveness of the policy.

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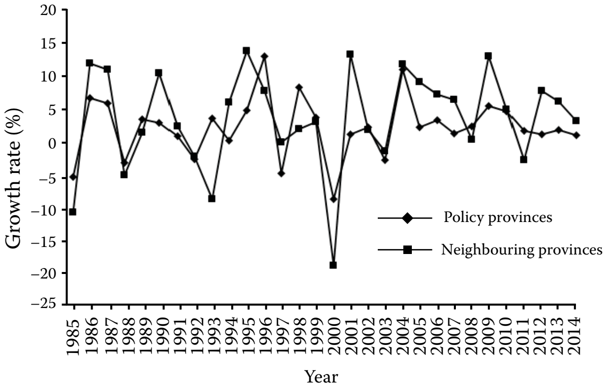

Figure 1. Growth rate of corn sown area in provinces where corn stockpiling policy was implemented and neighbouring provinces

Source: Compiled by the authors

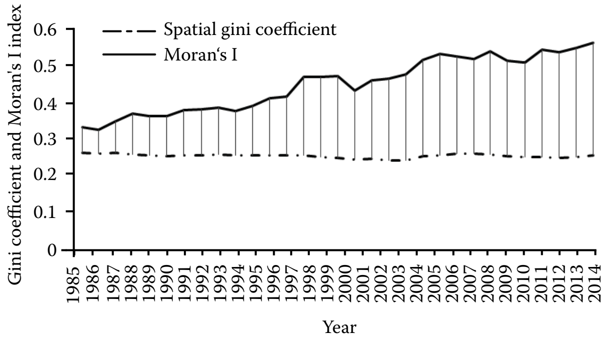

Figure 2. Spatial Gini Coefficients and Moran's I index (1984–2014)

Source: Authors' own processing

MATERIAL AND METHODS

Spatial Durbin Model. To confirm the spatial correlation of corn planting, we calculated the spatial Gini coefficient and Moran's I index for corn acreage respectively. The spatial Gini coefficient is given by:

$$Gini = \frac{1}{2\mu}\sum_{i=1}^{N}\sum_{j=1}^{N}(x_i - x_j)w_{ij} \quad (1)$$

where: x_i and x_j – values of the variable of interest in regions i and j respectively; w_{ij} – element of spatial weight matrix, defining the spatial relationship between regions i and j, where w_{ij} – 1 if regions i and j are neighbors; w_{ij} – 0 otherwise; N – total number of regions.

The Moran's I index is given by:

$$\text{Moran´sI} = \frac{N\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{W\sum_{i=1}^{N}(x_i - \overline{x})^2} \quad (2)$$

where: $\overline{x}$ – mean of x; W – sum of all w_{ij}.

The spatial Gini coefficient remained stable during 1984–2014 (Figure 2), indicating strong spatial correlation and synchronous changes in corn planting areas among neighbouring regions. Meanwhile, Moran's I index showed a steady increase over the same period, suggesting that major corn-producing provinces tended to cluster together. Further analysis of the local Moran's I index for 2014 revealed significant positive spatial autocorrelation in Inner Mongolia, Jilin and Heilongjiang at the 95% significance level. This clustering reflects spatial agglomeration in corn planting areas in these provinces. In 1984, only Jilin exhibited significant local Moran's I values, indicating that spatial autocorrelation has intensified over time.

The spatial autocorrelation test consistently indicates significant Moran's I values at the 1% level across all years, justifying the use of spatial econometric models. Spatial correlation can arise from the dependent variable, independent variables, or error terms. The Spatial Durbin Model (SDM) is well-suited for capturing spatial dependence from multiple sources, making it an ideal framework for this study (Elhorst 2014).

The spatial effects analysed in this paper can be divided into two key components. The first is the spatial lag of the dependent variable, which reflects how the corn planting area in one region is influenced by planting decisions in neighbouring regions. This effect is driven by two primary mechanisms. First, shared natural conditions play a significant role, as corn production heavily depends on factors such as soil quality and climate. Adjacent regions often share similar natural conditions, leading to comparable agricultural planting structures and creating a correlation between corn planting areas in neighbouring regions. Second, economic interdependence influences this dynamic. When neighbouring provinces expand their corn planting areas, the supply of other crops may decrease, altering the relative profitability of different crops in the local region. This change in relative returns affects farmers' planting decisions and reinforces spatial interdependence.

The second component involves the spatial spillover effects of the temporary corn stockpiling policy. Since provinces operate within a unified domestic market,

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price changes caused by the policy in one region are transmitted to others through market mechanisms. For instance, if the temporary procurement price set by the government exceeds the market price, arbitrage opportunities may arise, leading to increased corn prices in non-policy regions until the price, plus transportation costs, equalises with the procurement price. This could incentivise an expansion of corn planting in non-policy regions. Conversely, if the policy increases the expected mean and decreases the variance of corn prices in policy-implementing regions, farmers in these regions may be encouraged to plant more corn. This expansion could lead to a relative decline in equilibrium prices, thereby reducing the incentives for farmers in non-policy regions to plant corn. Together, these two components capture the complex spatial dynamics of corn planting decisions influenced by natural, economic, and policy-related factors.

The feed industry also contributes to spatial spillovers. As industry expands, transportation costs for raw materials like corn became a critical factor, making it more profitable to grow corn near major feed production centres. This interdependence further reinforces the need for a spatial econometric framework.

Given that a province's corn planting area is influenced not only by neighbouring regions' planting areas but also by their implementation of the corn stockpiling policy and the development of their feed industry, the SDM provides an appropriate analytical framework.

Formally, the SDM is expressed as:

$$y_{it} = \lambda \sum_{Nj=1}^{N} w_{ij} y_{jt} + \sum_{k=1}^{K} \beta_k x_{k,it} + \\ + \sum_{k=1}^{K} \sum_{j=1}^{N} \theta_k w_{ij} x_{k,jt} + \rho t + \alpha_i + \varepsilon_{it} \quad (3)$$

where: y_{it}– corn acreage planting area (thousand ha); i – province; t – time; w_{ij} – element in the spatial weight matrix W; if province i and province j are adjacent, $w_{ij}=1(i \neq j)$; otherwise $w = 0(i \neq j)$, $x_{k,it}$ (k=1,...,4) – variables that affect corn planting; ρ – measures the impact of technical change; α_i – fixed effects; ε_{it} – idiosyncratic error term.

Variable selection. The proportion of corn used for direct consumption is small, and most of the corn is used for post-production deep processing (such as the production of feed, bioethanol, corn starch, etc.). Therefore, it can be considered that farmers grow corn not mainly for consumption, but for profit from sales. Therefore, factors affecting corn production profits will affect farmers' corn planting decisions. There are four variables affecting corn planting area include: the farmers' expectations of corn prices, the cost of production, the relationship between corn and associated industries, and the technical progress.

Corn stockpiling policy and farmers' price expectations

As corn is mainly used for feed production and industrial processing, and less for consumption, the decision of corn planting area for corn growers is mainly driven by the pursuit of maximising profits. In this case, the level and volatile of corn prices become important factors affecting farmers' decisions to plant corn. Before planting corn, the market price of corn is unknown, and farmers make judgments about future corn prices based on past experience and then make planting decisions based on current production costs. The implementation of the corn stockpiling policy will change farmers' expectations of future corn prices, thereby changing their planting behaviour and affecting the planting area of corn. Therefore, this study uses the mean and variance of expected corn prices to express the effect of the corn temporary storage policy.

Suppose that farmers' expectation of corn price p_{it} has a normal distribution with mean μ_{it} and variance, σ_{it}^2, where: i = 1,...,n – provinces and t = 1,...n; t – time.; μ_{it} – level of farmers' expectation; σ_{it}^2 – uncertainty of farmers' expectation.

According to the adaptive expectations hypothesis, the price expectation model of farmers can be expressed as:

$$E_{t-1}(p_{it}) = p_{i,t-1} + \alpha_i \quad (4)$$

Equation (4) indicates that the farmers' expectation of the corn price in time (before planting corn) is equal to the corn price in t–1($p_{i,t-1}$) plus their knowledge of the past price fluctuations (α_1), where: α – E(p^{it}–p^{it-1}). The farmers' expectation for the fluctuation of corn price in time t can be expressed as follows:

$$\text{var}(p_{it}) = \sum_{j=1}^{3} w_j \left[p_{i,t-j} - E_{t-j-1}(p_{i,t-j}) \right]^2 \quad (5)$$

where: w_j – weight.

In this paper, we set w_j (j=1, 2, 3) equal to 0.5, 0.33, and 0.17 respectively based on the study of Chavas and Holt (1990). These weights indicates that the farmers'

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expectation of the price fluctuation in mainly depends on the price fluctuation in t–1 because it has the highest weight. The impact of price fluctuations in t–2 and t–3 on farmers' expectations gradually decreased. And only the price fluctuation in the last three periods will have an impact on the farmers' expectation of the price in time t.

In the provinces that have implemented the policy of corn stockpiling policy, the random fluctuation of corn price has a lower limit. Therefore, in these provinces, farmers' expectations of corn prices have changed to truncated normal distribution.

Let $p_{l,it}$ represents the minimum purchase price of corn stipulated in the corn stockpiling policy, $e_{it} = (p_{l,it} - \mu_{it})/\sigma_{it}$ represents the standardised random variable. Then the expectation and variance of the corn price in policies area can be expressed as:

$$\mu_{it}^{TN} = E\left(p_{it} \mid p_{it} > p_{l,it}\right) = \mu_{it} + \sigma_{it}\phi\left(e_{it}\right)\big/Z_{it} \quad (6)$$

$$\sigma_{it}^{TN} = \sigma_{it}\left[1 - e_{it}\phi\left(e_{it}\right)\big/Z_{it} - \left(\phi\left(e_{it}\right)\big/Z_{it}\right)^2\right] \quad (7)$$

where: superscript of μ_{it}^{TN} and σ_{it}^{TN} – truncated normal distribution; $Z_{it} = 1 - \Phi(e_{it})$, in which $\Phi(.)$ – standard normal distribution function.

The cost of production

The cost of corn production can be estimated by farmers when making planting decisions and will directly affect the area farmers plant corn. In this regard, this study uses the corn production cost per hectare (USD/ha) to measure how production costs affect the area of corn planting.

Downstream industry and corn acreage

Corn consumption in China is mainly used for feed production, which is the primary source of feed for China's animal husbandry. In 2014, feed consumption accounted for 62.26% of total corn consumption, while industrial processing consumption accounted for 29.46%, and corn consumption for food and seed accounted for 7% and 3%, respectively.

For the feed industry, the transportation costs of corn and feed are important factors that affect its spatial layout. Therefore, the planting area of corn in a region will affect the decision of feed enterprises on site selection. Since the asset specificity of the feed industry is stronger than that of corn cultivation, it is difficult for feed companies to move once they select a production location. The distribution of feed companies will affect the spatial layout of corn cultivation. The production cost of feed includes the price of corn and the transportation cost of corn. Assuming that the corn produced in each region is homogeneous, the price that feed enterprises are willing to pay for corn is inversely proportional to the transportation cost of corn. Corn growers who are closer to feed enterprises can obtain higher prices for their corn sales, which, under other conditions remaining constant (other crop prices unchanged), will increase the price of corn relative to other crops and lead to an increase in the planting area of corn. The above analysis shows that there may be a mutually reinforcing relationship between feed production and corn planting area, which is further strengthened by the spatial agglomeration of the feed industry. Figure 3 shows a scatter plot between corn planting area and feed production, both variables taken in their natural logarithms (where feed production does not include aquafeed). By observing the scatter plot and the trend line of linear fitting, it can be found that there is a positive correlation between inter-provincial feed production and corn planting area, with provinces with higher feed production also having higher corn planting areas, and *vice versa*.

Technical progress

The ongoing introduction of novel corn varieties stands as a key pillar underpinning the sustained expansion of corn cultivation across China. Tong Pingya has meticulously documented the progressive evolution of corn hybrid selection within the country throughout the 20th century. For instance, Zhongdan No. 2 (Chinese Academy of Agricultural Sciences, China), released

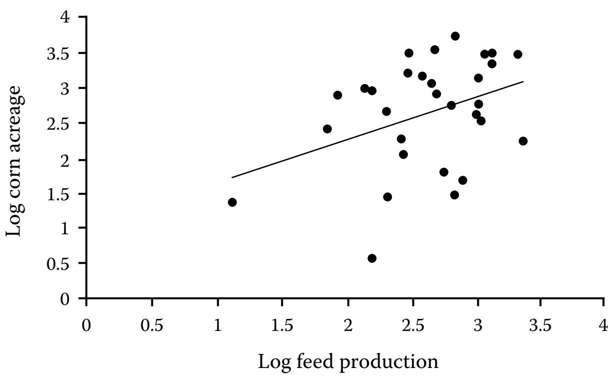

Figure 3. Corn sown area (thousand ha) and feed production (ten thousand ton) (2014)

Source: China Economic and Social Development Statistics Database and the 'China Feed Industry Yearbook' (China Feed Industry Association, 1985–2015)

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in the 1970s, ascended to prominence among the main varieties cultivated in the 1980s, attributed to its diminutive, robust stature and resistance to various diseases. With the advent of the 21st century, varieties such as Zhengdan 958 (Henan Academy of Agricultural Sciences, China) and Xianyu 335 (Pioneer Hi-bred Company, USA) gained widespread adoption for their compact structure and adaptability to dense planting, particularly favoured in regions cultivating spring corn due to their lower cumulative temperature requirements. Post 2010 saw the large-scale introduction and planting of new varieties including Jingke 968 (Beijing Academy of Agriculture and Foresty Science, China), Liangyu 99 (Deng Hai Liang Yu Seed Industry Company, China) and Tiannong 9 (Tian Nong Seed industry Co., China). Tiannong 9, for example, necessitates an active accumulated temperature of approximately 2 570 °C, distinguishing itself as a medium-maturing, high-starch variety with superior yield per unit area. Given its lower temperature requirement compared to traditional varieties, it has been widely promoted in the medium-maturing corn zones of Jilin Province, further expanding the province's corn cultivation area. These instances underscore the pivotal role of introducing new corn varieties in augmenting the corn planting expanse in northern regions, simultaneously highlighting the perennial and ongoing nature of technological advancements in corn cultivation. Consequently, a time variable may serve as an instrumental indicator of technological progression in corn varieties.

Technological advancement is recognised as a contributing factor to the spatial aggregation of industries. However, when assessing the spatial spillover effects of introducing new corn varieties, it is imperative to observe two considerations. Firstly, this paper employs time variables as proxies for technological progression, implying such advancements are ubiquitous across all provinces rather than isolated to specific locales. Secondly, given the geographically bound applicability of corn varieties, the spatial spillover effect of technological advances might be constrained. Hence, in the interpretation of subsequent regression analyses, the parameters associated with technological advancement and its spatial spillover effects necessitate cautious consideration.

According to the previous analysis, corn planting area is set as the dependent variable, the mean and variance of expected corn prices as the pivotal independent variables in the econometric model to assess the influence of the corn storage policy on the spatial and temporal distribution of corn cultivation. Concurrently, variables such as feed output, corn production cost per acre, and technological advancement over time are incorporated as control variables within the model.

Data sources and descriptive statistics

The data is sourced from various outlets. Information on corn planting area is obtained from the China Economic and Social Development Statistics Database online data map (National Bureau of Statistics, 1984–2014), while feed production data is extracted from the 'China Feed Industry Yearbook.' (China Feed Industry Association 1985–2015). Details about corn sales prices and production costs per acre are derived from the 'Compilation of Cost and Benefit Data of National Agricultural Products' and the 'Compilation of Cost and Benefit Data of Major National Agricultural Products Since the Founding of the People's Republic of China.' The minimum corn purchase price specified in the temporary corn reserve policy is obtained from the announcements of the National Development and Reform Commission (NDRC 2008–2016) over the years. Given that feed production data for each province and region is only accessible post 2001, this article focuses on the analysis timeframe from 2001 to 2013. Descriptive statistics for the above variables are shown in Table 1.

It should be noticed that the implementation of corn stockpiling policy is not random and may lead to sample selection bias (Huang and Yang 2017). It can be assumed that the non-randomness of corn stockpiling policy implementation is related to the characteristics of each province and further assume that these characteristics do not change over time. For example, the reason for implementing corn stockpiling policy in the four northeastern provinces is that these four provinces have unique geographical conditions suitable for large-scale corn planting. And these geographical conditions do not change over time. These time-invariant characteristics can be included in fixed effects. Therefore, Equation 3 should be estimated in the fixed effect panel data setting.

Another potential endogenous problem in estimating Equation 3 is due to the mutual influence between the feed industry and corn planting as we have discussed before. To address the endogeneity issue of feed production in the regression model, we introduced regional gross domestic product (GDP) as an instrumental variable for feed production. Below, we provide a detailed explanation of why GDP is a suitable instrument.

Firstly, GDP satisfies the relevance condition for an instrumental variable, as it is strongly correlated with feed production. Data from the 2014 Statistical Yearbook reveal a correlation coefficient of 0.76 between feed pro-

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Table 1. Descriptive statistics of variables

Variable name	Measuring unit	The whole nation		Policy implementation areas	
		mean	variance	mean	variance
Corn acreage planting area	thousand ha	1 433.406	1 083.990	2 657.145	996.855
Feed production	ten thousand ton	460.769	473.156	490.830	303.620
Corn production cost per hectare	USD	63.750	32.470	59.390	28.790
Mean of expected corn price per ton	USD	171.550	55.560	166.690	61.260
Variance of expected corn price	–	348.460	310.590	128.110	135.970

Source: China Economic and Social Development Statistics Database, 'China Feed Industry Yearbook', 'Compilation of Cost and Benefit Data of National Agricultural Products' and 'Compilation of Cost and Benefit Data of Major National Agricultural Products Since the Founding of the People's Republic of China'

duction and GDP across provinces, which is statistically significant at the 1% level. This indicates that regions with higher GDP levels are more likely to produce greater quantities of feed, driven by increased livestock production and related feed demand.

Secondly, GDP satisfies the exclusion restriction condition, as it is largely unaffected by corn planting areas. The correlation coefficient between GDP and corn planting area is only 0.18, which is not statistically significant. This suggests that variations in corn planting areas contribute minimally to regional GDP, given the relatively small share of corn cultivation in the overall economy.

The theoretical basis for using GDP as an instrumental variable is also robust. GDP influences feed production indirectly through its impact on livestock product demand. As normal goods, the demand for livestock products increases with rising *per capita* disposable income. Regional GDP reflects both *per capita* disposable income and population size, capturing the aggregate demand for livestock products. Since livestock products are perishable and costly to transport over long distances despite advancements in cold chain logistics, livestock production tends to be concentrated near consumption markets. Feed enterprises align their locations with the spatial distribution of livestock production to minimise transportation costs for raw materials (e.g. corn) and finished feed products. As a result, regional GDP indirectly drives the spatial distribution and scale of feed production.

Conversely, changes in corn planting areas have negligible effects on GDP due to the relatively minor economic contribution of corn cultivation in most provinces. This ensures that GDP remains exogenous to the regression equation, fulfilling the criteria for a valid instrumental variable.

In the estimation, we firstly multiply the dependent and independent variables by the spatial weight matrix. Then, we use the within transformation of panel data to remove the influence of fixed effects. After that, we estimate the transformed model using the two-stage least squares (2SLS) method.

EMPIRICAL RESULTS

Data sources

The data used are from multiple sources. The corn planting area data are from China Statistical Yearbook (The National Bureau of Statistics of China 2016–2020). The information on the price of corn and the unit production cost of 20 corn production provinces is derived from the Compendium of Cost and Benefit Information of National Agricultural Products (NDRC 1985–2015) and Compendium of Cost and Benefit Information of National Major Agricultural Products Since the founding of the PRC. The minimum corn purchase price stipulated by the corn temporary storage policy is collected from the announcement of the National Development and Reform Commission (NDRC 2008–2016) over the years. The feed production data are from China Feed Industry Yearbook (China Feed Industry Association 1985–2015). Since only the data of feed production of provinces after 2001 can be obtained, the time range of analysis limited to the period between 2001 and 2014.

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Regression results

The regression results of equation (5) are given in Table 1. First of all, the parameter λ is significant, indicating the existence of spatial spillover effect, that is, the corn planting area in one province has been affected by the neighbouring provinces. The source of this influence can be explained by the connection between corn and feed industry, production cost, mean and variance of expected corn price and technological progress. The coefficients of each variable cannot be directly interpreted as marginal effects in the spatial Durbin model (Lesage 2014) From Equation (1), the marginal effect of x_k can be expressed as:

$$\frac{\partial y}{\partial x_k} = \left(I_n - \hat{\lambda} W\right)^{-1} \left(\hat{\beta}_k I_n + \hat{\theta}_k W\right) \tag{8}$$

The marginal effects of technological progress are:

$$\frac{\partial y}{\partial T} = \left(I_n - \hat{\lambda} W\right)^{-1} \left(\hat{\rho} I_n\right) \tag{9}$$

Derived from Equations (6) and (7) is a matrix of $N \times N$, the sum of the i^{th} column in the matrix represents the sum of the impacts of a unit change of $x_{k,i}$ on the corn planting area of all provinces and regions, called the total effect (Lesage and Pacer 2009). The mean of total effect over N provinces is the average total effect. The average value of the main diagonal elements of the matrix represents the average direct effect (i.e. the average effect of $x_{k,i}$ change on the corn planting area of the province). The average indirect effect can be obtained by subtracting the average direct effect from the average total effect, which is the average influence of $x_{k,i}$ on the corn planting area of all other provinces.

From Table 2, it can be seen that both the average direct and indirect effects of feed production are negative. In other words, as the feed production in a province increases, the corn planting area in that province and neighbouring provinces decreases. Although Figure 3 shows a positive correlation between corn planting area and feed production, after controlling for the endogenous relationship between corn planting area and feed production using instrumental variables in 2SLS, the relationship becomes negative. This may be because after using instrumental variables, the variation in feed production that explains the variation in corn planting area is entirely caused by changes in GDP. During the period of 2001–2014, provinces with larger increases in GDP had smaller increases in corn planting area, while provinces with smaller increases in GDP had larger increases in corn planting area.

The increase in unit production costs of corn will reduce farmers' willingness to plant, resulting in a decrease in corn planting area not only in the province but also in neighbouring provinces. This may be because material costs and agricultural labour wage, which constitute the majority of production costs of corn, may show a common trend of change among neighbouring provinces. Material costs measure the cost of intermediate inputs such as fertilisers, pesticides and fuel, and these input factors may exhibit synchronous changes. Labor costs are calculated based on the *per capita* net income of rural residents in the previous year (Tian et al. 2020).

Table 2. Impact of corn stockpiling policy on corn acreage

Variables	Coefficient	Standard error	Z-value	P-value
Feed production	0.10	0.37	0.28	0.78
Unit production cost of corn	–5.77	2.51	–2.30	0.02
Mean of expected corn price	7.17	3.77	1.90	0.06
Variance of expected corn price	–0.25	0.10	–2.43	0.02
Spatial weighted feed production	–0.70	0.53	–1.32	0.19
Spatial weighted unit production cost of corn	3.66	2.98	1.23	0.22
Spatial weighted mean of expected corn price	–6.73	5.51	–1.22	0.22
Spatial weighted variance of expected corn price	0.56	0.22	2.58	0.01
Time (t)	31.10	24.30	1.28	0.20
Intercept term	–217.71	170.91	–1.27	0.20
λ	0.90	0.14	6.46	0.00

Source: Compiled by the authors

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Table 3. Spatial marginal effects

Variables	Average direct effect	Average indirect effect	Average total effect
Feed production	−0.38 (−0.67; −0.10)	−5.59 (−11.55; −1.35)	−5.97 (−12.22; −1.45)
Unit production cost of corn	−6.97 (−7.70; −6.28)	−14.01 (−28.95; −3.39)	−20.99 (−36.66; −9.67)
Mean of expected corn price	6.96 (6.82; 7.08)	−2.54 (−5.25; −0.62)	4.41 (1.57; 6.47)
Variance of expected corn price	0.02 (−0.14; 0.18)	3.08 (0.75; 6.37)	3.10 (0.61; 6.55)
Technical progress	53.10 (40.36; 66.45)	255.95 (61.93; 528.83)	309.05 (102.35; 95.28)

Figures in brackets are 95% confidence intervals
Source: Compiled by the authors

In recent years, *per capita* net income of rural residents has been rising in every province. This suggests that the spatial spillover effect of corn production costs may reflect the spatial correlation of production costs.

An increase in farmers' expectations of corn prices will increase the corn planting area in the province, which is consistent with expectations. However, changes in corn price expectations in one province have no significant effect on the corn planting area in neighbouring provinces (0 falls within the confidence interval of the average indirect effect of corn price).

However, both the average direct and indirect effects of variance of expected corn price are significant. On the one hand, the greater the uncertainty of farmers' expectations of corn prices (the larger the variance of expected corn price), the lower their willingness to plant and the smaller the corn acreage. This reflects that corn farmers are risk averse. On the other hand, an increase in the uncertainty of corn price expectations in one province will lead to an increase in the corn planting area in neighbouring provinces. The corn stockpiling policy increases the average corn price in the areas where the policy is implemented and reduces the fluctuation (variance) of corn price, thus increasing the corn planting area in these provinces. The corn stockpiling policy also has a spatial spillover effect. As the average indirect effect of corn price variance is positive, the decrease of corn price variance reduces the corn planting area in neighbouring provinces.

The impact of technological progress is also as expected. The introduction of new varieties will continuously expand the corn planting area. Since this study uses time variables as proxy variables for technological progress, technological progress in all provinces exhibits a common trend of change, which leads to high spatial correlation and significant spatial spillover effects.

From the results presented in Table 2, it can be observed that the spatial spillover effect of the expected price of corn is not significant, whereas the variance of the expected price of corn exhibits a significant spatial spillover effect. Subsequently, we tested whether the variance of the expected price of corn significantly affects the expected price and variance of the expected price in neighbouring provinces.

First, we used the expected price of corn as the dependent variable, incorporating unit production costs, feed production, and the variance of the expected price of corn into the regression model. A spatial Durbin model was employed to estimate the model, and the results indicate that the variance of the expected price of corn does not exhibit a spatial spillover effect.

Second, we used the variance of the expected price of corn as the dependent variable, adding unit production costs, feed production, and the expected price of corn into the regression model. A spatial panel data model with two-way fixed effects was then estimated using the maximum likelihood method, with results shown in Table 4. The results reveal that the coefficient λ is significantly negative, indicating that an increase in the variance of the expected price of corn in neighbouring regions reduces the variance of the expected price of corn in the local region, and *vice versa*.

This effect is attributed to the temporary corn storage policy, which reduced the variance of the expected price of corn in regions where the policy was implemented,

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Table 4. Spatial correlation test of the variance in corn expected prices

Variables	Coefficient	Std. error	*T*-value	*P*-value
ln(cost)	−1.1240	0.6605	−1.7019	0.0888
ln(feed)	0.3292	0.2589	1.2717	0.2035
ln(expp)	0.7179	0.6791	1.0572	0.2904
λ	−0.1776	0.0864	−2.0545	0.0399

Source: Compiled by the authors

thereby increasing the variance of the expected price of corn in neighbouring regions. From the regression results in Table 2, it can be observed that this increase in the variance of the expected price of corn in neighbouring regions leads to a reduction in corn planting areas in those regions.

For the temporary corn stockpiling policy, as the policy reduces the variance of the expected price of corn in the provinces where it is implemented, it consequently increases the variance of the expected price of corn in neighbouring provinces. This leads to a decrease in corn planting areas in neighbouring provinces.

A simulation of the effect of corn stockpiling policy

Based on the regression results, we can analyse the impact of the implementation and cancellation of the corn stockpiling policy. Since the corn stockpiling policy is only implemented in some provinces, we cannot obtain marginal effects of policy changes for each province. However, we can obtain the average direct effect of implementing this policy in provinces and its average indirect effect on other regions when the corn stockpiling policy changes. Thus, we can determine the impact on the national corn planting area when the corn stockpiling policy is cancelled in the four provinces.

After calculation, if the corn stockpiling policy had not been implemented after 2007, for provinces that implemented these policies: Inner Mongolia's average annual corn planting area would have decreased by 46.68 thousand ha, Liaoning by 24.97 thousand ha per year, Jilin by 51.38 thousand ha per year, and Heilongjiang by 68.56 thousand ha per year. The corn planting area in other provinces would have increased by approximately 10 thousand ha per year. The sum of all province's effects is an annual growth of 1.58 thousand ha. In other words, compared to not implementing the corn stockpiling policy, after its implementation, the national corn planting area increases by 1.58 thousand has per year. This increase is negligible compared to the total national corn planting area!

The corn stockpiling policy was cancelled in 2016 and replaced by a producer subsidy system. The implementation areas of the producer subsidy system are still these four provinces (Heilongjiang, Jilin, Liaoning and Inner Mongolia). The producer subsidy system provides subsidies to farmers based on their corn cultivation area in order to reduce interference with market prices. Although the producer subsidy system does not directly affect the market price of corn, it still indirectly affects the market price of corn through its impact on farmers' production decisions. This subsidy is equivalent to providing cost subsidies to corn farmers in these regions, reducing their production costs. Since there is currently no specific data on subsidy amounts, we cannot predict the effect of this policy from a numerical perspective. However, based on the regression results from Table 2, a decrease in unit production costs of corn will increase the corn planting area in regions where the subsidy is implemented. Since the producer subsidy system does not reduce production costs by lowering input prices, the corn planting costs in other provinces will not decrease synchronously. The impact of corn producer planting subsidies on other provinces still requires further investigation. However, it is certain that this policy promotes an expansion of the corn planting area in implementing provinces.

DISCUSSION

This study investigates the spatial spillover effects of China's corn stockpiling policy, focusing on its impact on farmers' price expectations and corn planting decisions. Our results reveal that the policy significantly increased corn planting areas in the implementing regions while reducing planting areas in non-targeted regions due to negative spatial spillover effects. These findings underscore the critical role of price expectations and their volatility in shaping farmers' planting behaviour.

Our analysis shows that while the mean of expected corn prices primarily affects planting decisions within the policy-implementing regions, the variance of expected prices exhibits both direct and indirect effects. Lower price volatility in targeted regions incentivised farmers to expand corn acreage, whereas increased volatility in neighbouring regions discouraged expansion, demonstrating the spatial reach of policy-induced market distortions.

These findings align with previous research emphasising the importance of price expectations in agricultural decision-making (Nerlove 1958; Chavas and

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Holt 1990). However, this study extends the literature by introducing spatial econometric models to account for spillover effects, which have largely been overlooked in previous studies (Fan et al. 2016; Gu and Guo 2017). Unlike earlier work focusing solely on direct policy impacts, this paper identifies indirect effects through interregional price linkages, offering a more comprehensive understanding of agricultural policy impacts.

The results emphasise the need for policymakers to consider spatial spillovers when designing and evaluating agricultural policies. The corn stockpiling policy created unintended consequences in non-targeted regions, highlighting the importance of integrated policy frameworks that account for regional interactions. Policy makers should aim to balance support for targeted regions with measures that mitigate adverse effects on neighbouring areas.

Moreover, the transition to a producer subsidy system after the policy's cancellation suggests a shift toward market-oriented mechanisms. Future policies should focus on minimising distortions while providing targeted support to regions with comparative advantages in corn production. Policymakers may also benefit from incorporating spatial econometric analyses to anticipate and address spillover effects in advance.

Despite its contributions, this study has several limitations. First, the analysis assumes that spatial spillovers operate primarily through price expectations, potentially overlooking other mechanisms, such as labour mobility and infrastructure development. Second, the spatial Durbin model assumes fixed spatial relationships, which may not fully capture dynamic interregional interactions over time. Future research could address these limitations by incorporating more flexible modelling approaches and additional explanatory variables.

CONCLUSION

This study analyses the impact of China's corn stockpiling policy on corn planting areas, focusing on the spatial spillover effects generated by changes in farmers' price expectations. Using a panel spatial Durbin model, we find that while the impact of corn price mean is limited to the local area, the variance of corn price expectations affects corn planting in the local and neighbouring areas. This indicates that the impact of the corn stockpiling policy spread throughout the country through price spillovers, contributing to the understanding of spatial effects in agricultural policy.

Our simulation analysis shows that the policy increased corn planting areas in the provinces where it was implemented. However, due to the spatial spillover effect, it negatively impacted corn planting in other provinces. The cancellation of the corn stockpiling policy would lead to a slowdown in corn planting growth in the implementing provinces, while other provinces would see an increase in planting areas. This suggests that while the cancellation may reduce planting in the targeted provinces, its overall effect on national planting areas could be limited. Following the cancellation of the policy, a producer subsidy system was implemented in the three northeastern provinces and Inner Mongolia. This system is expected to increase corn planting in the targeted provinces. However, the overall impact of the subsidy system will depend on which effect dominates, the negative impact of cancelling the stockpiling policy or the positive effect of the producer subsidy. The spatial effects of the producer subsidy system on other provinces require further investigation.

Our study highlights the need for further research into the spatial spillover effects of agricultural policies and their interaction with regional agricultural structures. A particularly fruitful direction for future work would be to investigate how different policy frameworks and institutional arrangements influence the success of agricultural interventions across various regions. This would involve both theoretical and empirical studies on the organisation of regional agricultural markets, as well as an in-depth examination of how local socio-economic factors, such as labour markets, infrastructure and agricultural practices affect the outcomes of these policies. By gaining a clearer understanding of these dynamics, we can design more effective policies that not only enhance local agricultural productivity but also drive sustainable growth at the regional and national levels.

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