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An Empirical Analysis of the Role of Forage Product Trade on Grassland Quality and Livestock Production in China

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Abstract: The restoration of grassland ecosystems and the development of the livestock industry in China are constrained by a gap in livestock feed supply and demand. The importation of forage products, as an important means to bridge this feed gap, deserves attention for its relationship with grassland quality and livestock production. This paper empirically examines the relationship between forage products trade and grassland quality, as well as livestock production. The paper uses a cointegration test and error correction model based on data on forage product trade, grassland quality, and livestock production in seven livestock-type regions from 2006 to 2020. The results show that forage product trade has a long-term stable equilibrium relationship with grassland quality in China. The relationships between forage product trade and livestock production in different livestock-type regions are heterogeneous. Among these heterogeneous results, livestock production in the Qinghai-Tibet Plateau region, Loess Plateau Region, Southwest Mountain Region, and Northeast Region are closely related to forage product trade. It appears that importation of feed reduces pressure on natural grasslands, as well as providing high-quality feed that improves livestock production. The above findings can help explain the characteristics of livestock production in different livestock-type regions in China, as well as provide empirical evidence and new ideas for restoring grassland environments and developing herbivorous animal husbandry.

Keywords: forage product trade; grassland quality; livestock production; cointegration relationship

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1. Introduction

China is one of the countries with the richest grassland resources in the world. The total area of grassland is nearly 400 million hectares, accounting for 40% of the country's total land area. As the largest terrestrial ecosystem in China, grasslands are the main barrier to national ecological degradation and the foundation of China's pastoral development [1,2]. Grassland pastures have an important strategic position in China's sustainable development [3]. However, due to long-term exploitation, China's grasslands face severe land degradation [4], loss of biodiversity [5,6], vegetation productivity decay [7], prominent grass–livestock conflicts [2], and low production efficiency of livestock products [8,9]. Both ecological and production functions have been seriously reduced [10], so enhancing the sustainable capacity of grasslands has become an important part of national development strategies. Numerous studies on the causes of grassland degradation have shown that climate change and human activities are the basic underlying drivers of degradation [11], while human-induced factors, such as overgrazing, are the main cause of low productivity [8,12]. With the increase in Chinese residents' demand for high-quality meat, eggs, and milk [13], and herders' pursuit of economic efficiency, herders are increasing their output of livestock products through more grazing. However, the limited production of forage in natural grasslands makes it difficult to meet the huge demand. The lack of forage is not only an important cause of grassland environmental problems, but also a major obstacle to the development of the livestock industry [14]. While there has been research on the feed supply and demand gap in China, including trade in forage products as an important means to supplement the feed gap, few studies have focused on the relationship between forage product trade and grassland ecology and livestock development. Because an increase in imported animal feed can reduce pressure on natural grazing land and provide high-quality feed for the livestock industry, this paper examines the relationship between importation of feed and two outcomes: grassland quality and livestock production.

On the one hand, accelerating the development of China's grass industry and significantly increasing the productivity of China's grasslands are fundamental measures to solve the country's severe shortage of animal feed [15,16]. On the other hand, imports of forage products are another important source of feed products supply in China. Although China's forage supply capacity has been significantly improved, it is difficult to meet the strong domestic demand due to the feed-supply sector's late start, slow development, and rather small industry scale. Therefore, imports from the international market are needed to fill the gap [17,18]. As an important means to alleviate the feed shortage problem in China, trade in forage products can improve the grassland environment by increasing the available forage so that herders can reduce overgrazing. At the same time, the supply of high-quality forage can improve feeding patterns, enhance livestock production efficiency, and promote the sustainable development of the domestic grass-fed livestock industry [19]. Therefore, it is important to empirically examine the role of forage product trade with respect to both grassland quality and livestock production in China, in order to bring into play the economic and ecological values of forage trade, improve the grassland ecology, and promote herbivorous animal husbandry.

A large number of studies have been conducted on the development of livestock husbandry and grassland ecological quality in China, including analyses of the current situation, evolutionary characteristics, and different regions. The current research on the import and export trade of grass products mainly addresses trade characteristics and trade competitiveness. In addition, the relevant research also covers import and export trade policies. While many studies have highlighted the deficiencies and dilemmas of China in grass production, researchers believe that forage product trade can effectively bridge the gap between supply and demand in the domestic forage product market, improve the environment, and promote the sustainable development of the entire domestic agricultural sector [18,20,21]. However, few articles have specifically analyzed the relationship between the forage product trade, grassland ecological environment, and grass-fed animal husbandry, and even fewer empirical analyses have been conducted.

Based on the division of China's livestock industry into seven geographical types, this paper empirically tests the relationship between forage product trade, the grassland environment, and the different regional grass-fed livestock industries, through data on China's forage product trade, livestock production, and grassland quality from 2006 to 2020. The contributions of this paper are to empirically examine the role of forage product trade from the perspective of the feed gap; to provide references for the characteristics of livestock production in different livestock type regions; and to propose a new thought direction for grassland ecological improvement, as well as promoting the livestock industry's development from the perspective of foreign trade.

The rest of this paper is organized as follows. Section 2 provides a background on the current status of the forage product trade, grassland ecological improvement, and livestock development. Section 3 introduces the data sources and methods. Section 4 conducts the analysis and presents the results. Section 5 provides a robustness test and further discussion. Section 6 contains the main conclusions and policy implications.

2. Background

2.1. Current Status of Trade in Forage Products

With the booming development of China's dairy industry and the increasing demand for beef and lamb, high-quality forage grass is indispensable for the production of safe, high-quality meat and dairy products. Although the development of the domestic forage industry has achieved remarkable results, due to its late start and small scale, the domestic production of forage grass is far from meeting the huge demand, and there is a need to import a lot of high-quality forage from abroad to supply the domestic demand. According to the statistical data of the National Bureau of Statistics, the national herbivorous livestock feeding capacity in 2019 was about 1.31 billion sheep units, of which 270 million sheep units can be fed by natural grassland and 180 million sheep units can be fed by existing intentionally planted grasses. About 66% of herbivorous livestock do not have a stable source of high-quality forage supply. The domestic forage gap is mainly solved by feeding straw and other lower-quality agricultural resources, increasing the proportion of cereal feed, and importing feed from abroad [22].

China's imports of forage products have been growing quickly in recent years. Exports have been at a low level for a long time and show a downward trend. The import volume was 0.02 million tons in 2001, and increased sharply after 2008, reaching 1.93 million tons in 2017. Later, the quantity of imported forage products slightly decreased, affected by several factors, including Australia's drought and the trade friction between China and the US, when tariffs were imposed on imported alfalfa. After that, the import volume rose again in 2020, reaching a peak of 2.14 million tons in 2021. The import growth rate has shown an upward trend in recent years (Figure 1).

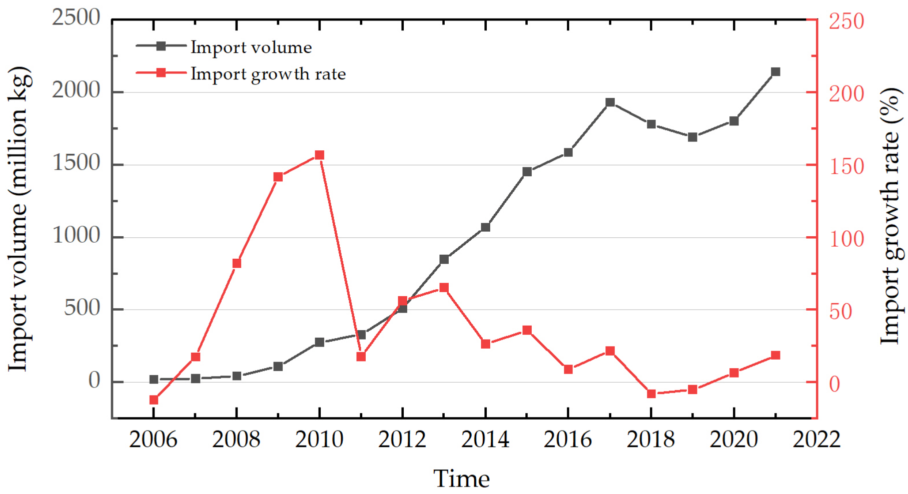

Figure 1. Import volume and import growth rate of forage products.

Imports of forage products are divided into two categories: forage grass and forage seed. The vast majority of imports are forage grasses, which account for more than 95% of the import share of forage products in the past five years. Import of forage grasses into China mainly comes from the United States (with imports in 2021 reaching 1.43 million tons, accounting for 70.14% of the total imports of forage grasses), followed by Spain and Australia, with imports of 274,366 tons and 212,156 tons, respectively; these three exporters account for 90% of China's total imports. Forage grasses are also imported from South Africa and Canada. Forage seed trade partner countries are more scattered, mainly from the United States, Denmark, and Canada.

2.2. *Status of Grassland Ecosystem*

Although China's grassland ecology is still fragile, it is steadily improving. For a long time, influenced by climate change as well as human factors, different degrees of degradation occurred in grassland pasture areas across the country. Overgrazing was common; available grasslands became degraded, sandy and saline to different degrees; water loss in grassland areas intensified; and the environmental carrying capacity was significantly reduced. All of this greatly reduced the production capacity of grasslands. In response, government policies have attached great importance to grassland ecological problems and made efforts to actively manage them. With the comprehensive promotion of grassland reform in China, the continuous improvement of various policies and measures to strengthen grasslands and benefit herding, and the expansion of major ecological projects, grassland ecological functions have been enhanced, grassland productivity levels have steadily increased, and the momentum of deterioration of the grassland ecology has been curbed. The comprehensive vegetation cover of grasslands nationwide has increased from 48% in 2016 to 56.1% in 2020, and the quality of grasslands has continuously improved (Figure 2).

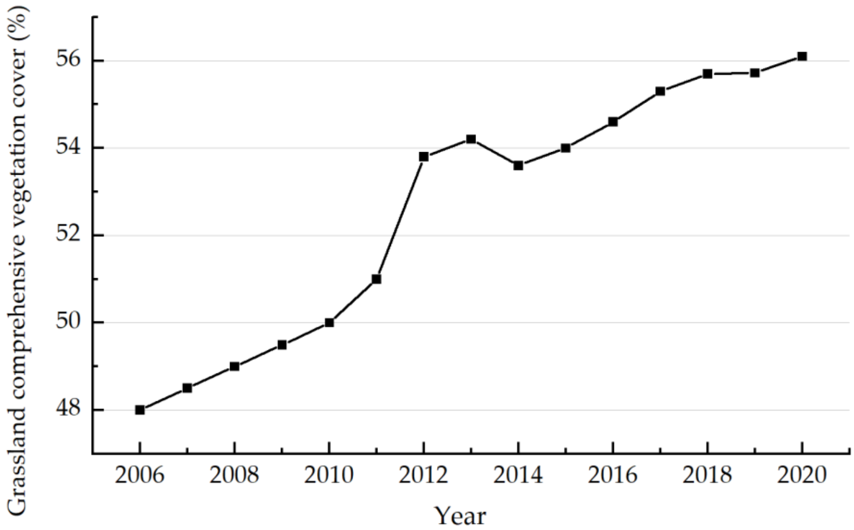

Figure 2. National grassland comprehensive vegetation cover.

2.3. Geographical Classification and Development of Livestock Industry

China's livestock industry covers a vast area, with obvious differences among different regions. In order to investigate the relationship between forage product trade and livestock production in different regions, this paper makes a geographical division of China's livestock industry with reference to the scheme of Comprehensive Zoning of China's Livestock Industry proposed by the Institute of Agricultural Zoning, Chinese Academy of Agricultural Sciences. Based on the principles and indicators of livestock zoning, and with consideration of regional differences in feed resources, natural environment, feeding technology, and social needs, as well as ethnic habits and production characteristics, this program divides China's livestock industry into seven livestock geographical regions, namely, Qinghai-Tibet Plateau Region, Mengxin Plateau Region, Loess Plateau Region, Southwest Mountain Region, Northeast Region, Yellow and Huaihai Sea Region, and East China Sea Region. Since the above regions are not divided according to provincial boundaries, there are cases where the same province belongs to two regions. In order to facilitate the study, this paper additionally re-divides the seven corresponding geographical types as research objects according to the provincial boundaries. The results of the division are shown in Figure 3 (the specific provinces included in each region are listed in Table A1 in Appendix A).

China's livestock industry has experienced rapid development since the 1980s. The growth rate of livestock production has far exceeded the world average, and the proportion of livestock output value to total agricultural output value has greatly increased. Looking at the situation of grass-fed animal husbandry, in the past ten years or so, the slaughter volume of cattle and sheep, the main grass-fed livestock in China, has increased rapidly. National cattle and sheep slaughtering increased by 25.58% from 2006 to 2020. In the seven zones, the slaughter volume ranges from high to low in the Mengxin Plateau Region, Yellow and Huaihai Sea Region, East China Sea Region, Southwest Mountain Region, Northeast Region, Loess Plateau Region, and Qinghai-Tibet Plateau Region (Figure 4). Except for the Yellow and Huaihai Sea Region, the other six regions basically show a fluctuating upward trend. Compared with 2006, the increase in cattle and sheep slaughtering in 2020 in each region was 62.00% in the Loess Plateau Region, 57.37% in the Southwest Mountain Region, 40.97% in the Mengxin Plateau Region, 30.96% in the East China Sea Region, 10.67% in the Qinghai-Tibet Plateau Region, and 9.01% in the Northeast Region. There was a decrease of 3.62% only in the Yellow and Huaihai Sea Region.

Figure 3. Division of the livestock geographical regions.

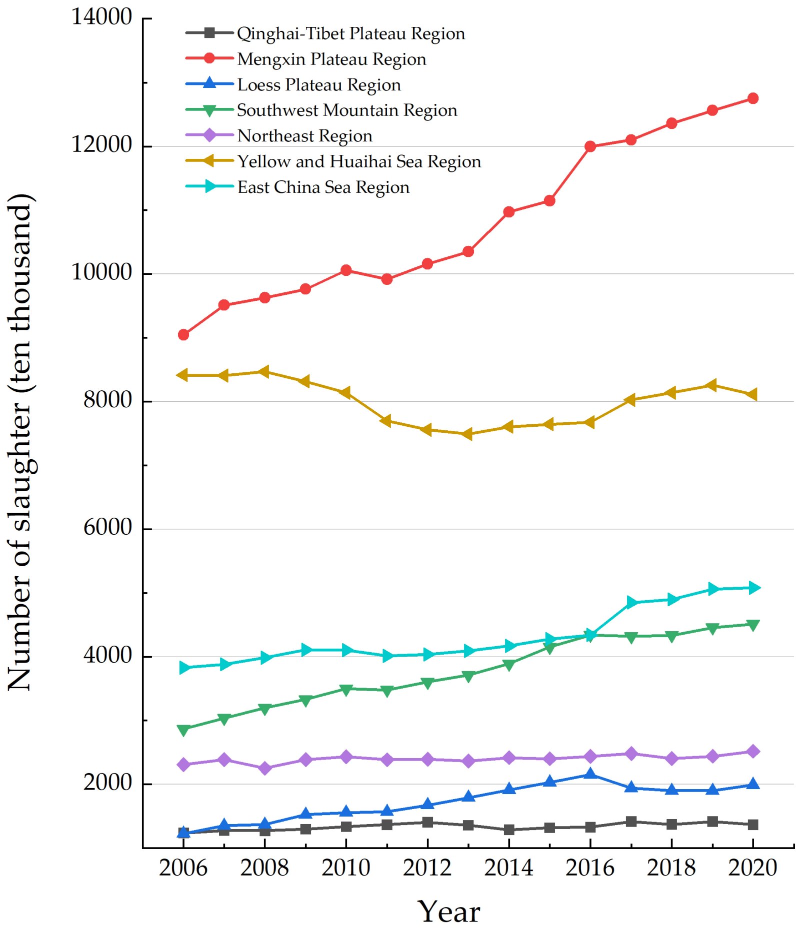

Figure 4. The amount of cattle and sheep slaughtered in each livestock region.

Although China's livestock industry has grown, there is still a gap between it and developed countries. There are still some constraints to achieving high-quality development in the livestock industry. In terms of forage resources, overgrazing in pastoral areas has triggered ecological degradation and low productivity of grasslands, and the forage industry in agricultural areas has still not been fully developed. As a result, the development of cattle, sheep, and other grass-fed livestock industries faces the problem of regional and seasonal shortages of high-quality forage, which restricts the expansion of the beef and sheep meat production scale and the optimization of the meat consumption structure [23].

3. Data and Methods

3.1. Data

In this paper, time series data from 2006 to 2020 were selected to explore the relationship between trade in forage products and the quality of grass and livestock production in China. The degree of forage product trade was measured by the import volume of forage products, including both forage and forage seeds, denoted by FPI_t. The data were obtained from the UN COMTRADE database. Grassland quality was measured by the comprehensive vegetation cover of grasslands in China, denoted by VC_t. These data were obtained from the National Grassland Inspection Report. Livestock production was measured by cattle and sheep slaughter; the total cattle and sheep slaughter in China is expressed by CSS_t. According to the geographical types of livestock husbandry classified above, the cattle and sheep slaughtering in the Qinghai-Tibet Plateau Region, Mengxin Plateau Region, Loess Plateau Region, Southwest Mountain Region, Northeast Region, Yellow and Huaihai Sea Region, and East China Sea Region are expressed by $CSS1_t$, $CSS2_t$, $CSS3_t$, $CSS4_t$, $CSS5_t$, $CSS6_t$, and $CSS7_t$, respectively, based on data from the National Bureau of Statistics, and the number for each district was obtained by summing up the provinces included in each district. In the robustness test in Section 5, the natural grassland stock-carrying capacity is denoted by SC_t and the data were obtained from the National Grassland Inspection Report. The total output value of the livestock industry is denoted by LIO_t, based on data obtained from the National Bureau of Statistics. In addition, in order to eliminate the heteroskedasticity in the time series data, the original variables were logarithmically treated and denoted as $lnFPI_t$, $lnVC_t$, $lnCSS_t$, $lnCSS1_t$, $lnCSS2_t$, $lnCSS3_t$, $lnCSS4_t$, $lnCSS5_t$, $lnCSS6_t$, $lnCSS7_t$, $lnSC_t$, and $lnLIO_t$.

3.2. Methods

Econometric modeling requires variables to be stationary, and non-stationary time series are prone to spurious regressions when using traditional econometric methods. In real life, most time series data are non-stationary. However, the linear combination of several non-stationary series may have the property of not varying with time, and this stationary linear combination indicates the existence of a long-run stable equilibrium relationship between these variables. In this paper, we want to investigate the relationship between forage product trade and both grass quality and livestock production. This is suitable for binary time series analysis. Therefore, under the condition that each time series is stationary and of the same order, the Engle and Granger (EG) two-step method suitable for the two variables was used to test whether the variables are cointegrated with each other; i.e., whether there is a stable equilibrium relationship in the long run. Next, the error correction model was built on the basis of cointegration to analyze the short-run relationship. Finally, a Granger causality test was conducted to examine the causal relationship between the variables.

3.2.1. Cointegration Test

A time series that has been differenced once into a stationary series is called a first-order single integer and is denoted as I(1). Suppose the two I(1) processes $\{y_t\}$, $\{x_t\}$ can be written, respectively, as

$$\begin{cases} y_t = \alpha + \beta w_t + \varepsilon_t \\ x_t = \gamma + \delta w_t + u_t \end{cases} \tag{1}$$

where w_t is random wandering, and $w_t = w_{t-1} + v_t$; and ε_t, u_t, v_t are white noise.

Since $\{y_t\}$ and $\{x_t\}$ share a common stochastic trend, w_t, the following linear combination of the two is a stationary process:

$$\delta y_t - \beta x_t = (\alpha\delta - \beta\gamma) + (\delta\varepsilon_t - \beta u_t) \tag{2}$$

where $(\alpha\delta - \beta\gamma)$ is a constant and $(\delta\varepsilon_t - \beta u_t)$ is a linear combination of white noise. $\{y_t\}$ and $\{x_t\}$ are said to be cointegrated, and the vector $(\delta, -\beta)$ is called the cointegrating vector or the coefficient of cointegration. Clearly, it is possible to normalize $(\delta, -\beta)$ to $(1, -\beta/\delta)$.

For the test of cointegration, Engle and Granger (1987) proposed the following "Engle and Granger-Augmented Dickey-Fuller (EG-ADF)" test.

The original hypothesis is that $\{y_t, x_t\}$ has a cointegration relationship and the coefficient of cointegration is $\{1, -\theta\}$.

If the original hypothesis holds, then $\{z_t \equiv y_t - \theta x_t\}$ is a stationary process. If θ is known, the Augmented Dickey-Fuller (ADF) test can be used to determine whether $\{z_t\}$ is stationary. If "$\{z_t\}$ is stationary" is accepted, then $\{y_t, x_t\}$ is considered to have a cointegration relationship. However, θ is usually not known, so the EG-ADF test is performed in two steps:

Step 1: Estimate the coefficient of cointegration θ using ordinary least squares (OLS); i.e.,

$$y_t = \varphi + \theta x_t + z_t \tag{3}$$

Under the original assumption that $\{y_t, x_t\}$ has a cointegration relationship, although $\{y_t, x_t\}$ is non-stationary, $\{z_t\}$ is a stationary process, so the OLS estimates $\hat{\varphi}$ and $\hat{\theta}$ are consistent estimates.

Step 2: An ADF test is performed on the residual series $\left\{\hat{z}_t \equiv y_t - \hat{\varphi} - \hat{\theta} x_t\right\}$ to determine whether it is stationary. Since the coefficients are estimated and not the true coefficients, the critical values of the EG-ADF statistic are different from the ordinary ADF test. The critical values in this paper refer to the critical values given by Stock and Watson (2012).

If the test result confirms that $\{\hat{z}_t\}$ is stationary, the original hypothesis that $\{y_t, x_t\}$ has a cointegration relationship is accepted. At this point, the estimated cointegration relationship "$y_t - \hat{\varphi} - \hat{\theta} x_t$" is the long-run equilibrium relationship between $\{y_t, x_t\}$.

3.2.2. Error Correction Model Construction

To estimate the short-term relationship between $\{y_t, x_t\}$, an error correction model was used. Under the premise that there is a cointegration relationship between $\{y_t, x_t\}$, substituting the residuals $\left\{\hat{z}_t \equiv y_t - \hat{\varphi} - \hat{\theta} x_t\right\}$ into the error correction model yields

$$\Delta y_t = \gamma_0 \Delta x_t + (\beta_1 - 1)\hat{z}_{t-1} + error_t \tag{4}$$

Estimates of the short-term parameters were obtained by estimating the above equation using OLS.

4. Results

4.1. Unit Root Test

The variables were tested to determine their stationarity and single integer order. In this paper, the ADF test, a conventional method of the unit root test, was used to determine the stationarity of the observations. Based on the time trend of the variables, it was determined whether to include a time trend term and a drift term in the ADF test. The maximum lag order suggested by Schwert (1989) was used to determine that the maximum lag order of the ADF test in this paper is 7. Using the sequential t-rule, the lag order is gradually reduced from the maximum lag order until the last order regression coefficient is significant, thus determining the optimal lag order. The test results are shown in Table A2.

The test results show that the ADF statistics of variables $lnFPI_t$, $lnVC_t$, $lnCSS_t$, $lnCSS1_t$, $lnCSS2_t$, $lnCSS3_t$, $lnCSS4_t$, $lnCSS5_t$, and $lnCSS7_t$ are all greater than the 10% critical value, indicating that the variables are non-stationary at the 10% significance level. After the first-order difference treatment, the ADF statistics of the above nine variables are all smaller than the 10% critical value. This indicates that the nine variables are stationary after differencing, all of them are first-order single integers, and the cointegration relationship can be further tested.

4.2. Cointegration Analysis

First, the coefficients were estimated using OLS, and the results are shown in Table A3. The residual series generated from each group of regressions are then subjected to unit root tests, and the residual series of each regression are denoted as R_VC_t, R_CSS_t, R_CSS1_t, R_CSS2_t, R_CSS3_t, R_CSS4_t, R_CSS5_t, R_CSS7_t, in that order. The test results are shown in Table A4.

The results show that the ADF statistics of the residual series R_VC_t, R_CSS1_t, R_CSS3_t, R_CSS4_t, R_CSS5_t are all less than the 5% critical value, indicating that all five residual series are stationary at the 5% significance level. Therefore, $lnFPI_t$ has a cointegration relationship with $lnVC_t$, $lnCSS1_t$, $lnCSS3_t$, $lnCSS4_t$, and $lnCSS5_t$, respectively. This indicates that there is a long-term stable equilibrium relationship between them. The results of the cointegrating equation are organized as follows:

$$lnVC_t = 3.837443 + 0.0330532\, lnFPI_t \quad (5)$$

$$lnCSS1_t = 7.126315 + 0.0191151\, lnFPI_t \quad (6)$$

$$lnCSS3_t = 7.065525 + 0.1001098\, lnFPI_t \quad (7)$$

$$lnCSS4_t = 7.902654 + 0.0869083\, lnFPI_t \quad (8)$$

$$lnCSS5_t = 7.739439 + 0.0117449\, lnFPI_t \quad (9)$$

The above regression coefficients are all significant at the 1% level. This indicates that there is a long-term stable positive equilibrium relationship between forage product trade and grassland quality as well as livestock production in the Qinghai-Tibet Plateau Region, Loess Plateau Region, Southwest Mountain Region, and Northeast Region, respectively. From the cointegrating equation, it is clear that each 1% increase in forage importation corresponds to a 0.033% increase in the grassland comprehensive vegetation cover, 0.019% increase in cattle and sheep slaughtering in the Tibetan Plateau Region, 0.100% increase in the Loess Plateau Region, 0.087% increase in the Southwest Mountain Region, and 0.012% increase in the Northeast Region. However, there is no long-term stable equilibrium relationship between forage product trade and cattle and sheep slaughtering in the whole country, nor in the Mengxin Plateau Region, Yellow and Huaihai Sea Region, or East China Sea Region.

4.3. Error Correction Model

The cointegration test indicates that there is a long-run equilibrium relationship between the variables. Therefore, the error correction model was developed to reveal the short-run dynamic relationship between the variables. The results of the error correction model are as follows:

$$d.lnVC_t = 0.0082987 + 0.0068959\ d.lnFPI_t - 0.5015439\ R\_VC_{t-1} \quad (10)$$

$$d.lnCSS1_t = 0.0017977 + 0.0177112\ d.lnFPI_t - 0.6969093\ R\_CSS1_{t-1} \quad (11)$$

$$d.lnCSS3_t = 0.0106294 + 0.0733106\ d.lnFPI_t - 0.6505343\ R\_CSS3_{t-1} \quad (12)$$

$$d.lnCSS4_t = 0.0219662 + 0.0307239\ d.lnFPI_t - 0.1482602\ R\_CSS4_{t-1} \quad (13)$$

$$d.lnCSS5_t = 0.0010603 + 0.006541\ d.lnFPI_t - 1.3516383\ R\_CSS5_{t-1} \quad (14)$$

The coefficients of the error correction term are significantly negative in each error correction model, which is consistent with the reverse correction mechanism. When the short-term fluctuations deviate from the long-term equilibrium, the disequilibrium state will be pulled back to the equilibrium state with the corresponding adjustment strength. Among them, the coefficients of $d.lnFPI_t$ are insignificant in most of the models, indicating that the short-term effects of forage imports on the comprehensive vegetation cover of grassland and cattle and sheep slaughtering are not significant, and the short-term fit is not as good as the long-term trend.

4.4. Granger Causality Test

A Granger causality test can be performed under the premise that there is a long-term stable equilibrium relationship between two time series economic variables X and Y. The concept of this relationship is as follows: if the prediction of variable Y with the inclusion of past information of variables X and Y is better than the prediction of variable Y with past information of variable Y alone (i.e., if the past information of variable X favors the prediction of information about Y and contributes to the change of Y), then variable X is said to be the Granger cause of variable Y. It is important to note that the relationship tests the temporal order of the variables in statistical terms and is not a test of true causality, so the absence of Granger causality does not mean that there is no causal relationship between the variables. The specific causality needs to be judged based on theory, experience, and models.

The results of the Granger causality test are shown in Table A5. The results show that there is unidirectional Granger causality between forage imports and grassland comprehensive vegetation cover at the 5% significance level. This indicates that the change in forage trade import volume can explain the change of grassland comprehensive vegetation cover. There is a one-way Granger causality relationship between forage imports and cattle and sheep slaughtering in the Qinghai-Tibet Plateau Region, and a two-way Granger causality relationship with cattle and sheep slaughtering in the Loess Plateau and Northeast Regions.

4.5. Summary

From the above results, there is a long-term and stable positive equilibrium relationship between forage product trade and grassland quality. The increase in forage trade imports is accompanied by a trend of better quality grassland. The positive relationship between them is long-term and stable. When the forage imports increased faster, the quality of the grassland improved faster, and when the forage imports increased slowly or decreased, the quality of the grassland improved more slowly or degraded. Although the causal relationship needs to be further identified, the above results suggest a strong relationship between forage products import and grassland quality. The reason may be that the import of forage products can reduce overgrazing and overexploitation of grasslands by providing an additional source of forage for herders, which helps restore the ecological capacity of the grassland resources. Grazing intensity has significant effects on grassland plant community composition and its quantitative characteristics, such as biomass, and on the soil properties. Studies have shown that, as grazing intensity increases, the vegetation cover and biomass of grasslands subsequently decrease, the community structure tends to simplify, and species succession is subject to drought and saline biology [24]. With increasing grazing intensity, the soil structure is degraded and the chemical composition (including the nutrient content of nitrogen, phosphorus, potassium, calcium, and magnesium) decreases. Grassland productivity and ecosystem function, which depend on plant diversity, also decrease [25–28]. A reduction in grazing intensity can increase the vegetation cover and biomass of grasslands and improve the soil properties. It helps bring into play the ecological values of grassland plants, such as purifying air and absorbing noise, reducing soil erosion and land desertification, and improving soil to enhance ground strength, water conservation, and climate regulation [10].

There is also a relationship between forage trade and livestock production, but heterogeneous patterns exist between different livestock regions. Among them, there is a long-term stable positive equilibrium relationship between forage product trade and livestock production in the Qinghai-Tibet Plateau Region, Loess Plateau Region, Southwest Mountain Region, and Northeast Region. The increase or decrease in the import of forage products is accompanied by an increase or decrease in livestock production in these regions, with stable changes over time. Similarly, although the causal relationship between the two cannot be precisely identified, there is a strong relationship between livestock production and forage imports in the four types of regions mentioned above. The reason may be that the supply of high-quality forage can address the shortcomings of the livestock industry, including high consumption, low output, and poor ability to withstand natural risks. China's traditional farming and herding industry relies on the "concentrate + straw" feeding model, mostly feeding straw and supplementing it with a little concentrate. This "staple food" of herbivorous livestock is not high-quality forage, resulting in low productivity and low marginal effect of forage conversion [17]. In contrast, there is no long-term stable equilibrium relationship between forage product trade and livestock production in the Mengxin Plateau Region, Yellow and Huaihai Sea Region, and East China Sea Region, indicating that livestock production in these regions is closely related to other factors, weakening the role of forage trade. With the vast area of China's livestock industry and many influencing factors, the relationship between forage trade and livestock production is also not stable in the long term from a national perspective.

5. Discussion

5.1. Robustness Test

In order to confirm the reliability of the results, this paper adopts replacement variables for robustness testing.

In terms of grassland quality, the natural grassland stock-carrying capacity was regressed on the comprehensive vegetation cover of grassland instead, and the cointegrating equation is as follows. The stock carrying capacity is the maximum quota of livestock that the grassland can carry during the yearly grazing period under moderate utilization. A higher natural grassland stock carrying capacity indicates a better grassland carrying capacity and reflects an improvement in grassland quality. After testing, there is still a long-term stable positive equilibrium relationship between forage product imports and natural grassland stock-carrying capacity, indicating a stable relationship between forage trade and grassland quality.

$$lnSC_t = 10.01614 + 0.0273085\, lnFPI_t \tag{15}$$

In terms of livestock production, a robustness test was conducted for the four regions with a cointegration relationship between livestock production and forage imports. The total output values of livestock in these regions were used as a proxy for cattle and sheep slaughtering. The total output values of the livestock in the four regions are denoted as

$LIO1_t$, $LIO3_t$, $LIO4_t$, and $LIO5_t$, and the cointegrating equations are as follows. After testing, there is still a long-term stable positive equilibrium relationship between the total livestock production value and forage product imports in the Loess Plateau Region, Southwest Mountain Region, and Northeast Region, and the coefficient magnitude relationship is consistent with the above. There is no cointegration relationship between the total output value of livestock and the import of forage products in the Qinghai-Tibet Plateau Region, indicating that the relationship between the livestock output and import of forage products in the Qinghai-Tibet Plateau Region is not as stable as that in the other three regions.

$$lnLIO3_t = 6.303712 + 0.1666335\, lnFPI_t \tag{16}$$

$$lnLIO4_t = 7.963237 + 0.1038807\, lnFPI_t \tag{17}$$

$$lnLIO5_t = 7.779597 + 0.100019\, lnFPI_t \tag{18}$$

5.2. Further Discussion

China's livestock region is vast, and livestock types can be broadly divided into three categories: first, purely pastoral areas, which are mostly pasture grazing; second, agricultural areas, which are mostly captive-bred; and third, semi-agricultural and semi-pastoral areas, which include both types of feeding. In order to explore the reasons for the differences in the relationship between forage product trade and different livestock geographical types, the seven livestock geographical types were combined into three areas for comparative analysis (Figure 5).

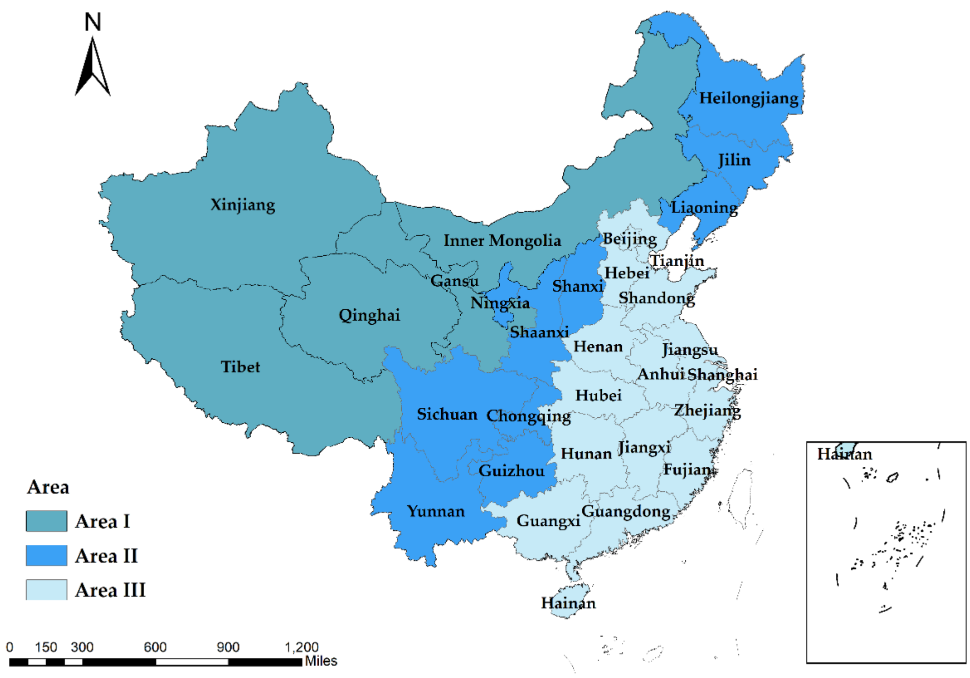

Figure 5. The three areas after combination of the seven livestock geographical types.

Area I includes the Qinghai-Tibet Plateau Region and Mengxin Plateau Region; Area II includes the Loess Plateau Region, Southwest Mountain Region, and Northeast Region; and Area III includes the Yellow and Huaihai Sea Region and East China Sea Region. The natural grassland of the three areas gradually decreases from the northwest to the central region to the southeast coast, and the level of management and scientific and technological development gradually rises.

Area I contains the five typical pastoral provinces in China with abundant natural grassland resources. The feeding method is mainly grazing, with a bias toward pastoral animal husbandry. Since livestock feed mainly comes from natural grasslands and relies little on imported forage, livestock production in this region is less affected by fluctuations in forage imports. There is a long-term stable equilibrium relationship between cattle and sheep slaughtering and forage product imports in the Qinghai-Tibet Plateau Region. This is in contrast with the Mengxin Plateau Region, indicating that livestock production in the Qinghai-Tibet Plateau Region is more closely related to forage imports. The reason may be that the Tibetan plateau has harsher natural conditions, more fragile ecosystems, and relatively scarce natural forage resources. Natural forage supply is unstable, so livestock production is more influenced by the amount of commercial grass imports.

Area II's Loess Plateau Region, Southwest Mountain Region, and Northeast Region have the most stable long-term equilibrium relationships between livestock production and forage product imports, and livestock and forage imports are highly correlated. The type of livestock farming in this area tends to be semi-agricultural and semi-pastoral, with a balance between pasture grazing and captive breeding. Compared to Area I, natural forage production is limited and therefore more dependent on imported forage, so the relationship between livestock production and forage trade is closer in this area.

Area III, comprising the Yellow and Huaihai Sea Region and the East China Sea Region, is located in the eastern coastal region of China and has the least natural grassland area compared to the first two areas. However, there is no long-term stable equilibrium relationship between livestock production and forage trade in this area. The reason may be that the livestock industry in this region is dominated by house feeding and semi-house feeding, with more intensive operation and a higher management level. The plains terrain and rich products can provide richer feed for animal husbandry, and there is more grain-based feeding. With a dense population and high demand for livestock products in the region, the development of the food-processing industry can also drive the development of animal husbandry. Faced with a more complex production environment, there are more factors affecting the production output, so the relationship with the trade of forage products is not obvious.

6. Conclusions and Implications

Based on the division of China's livestock industry into seven livestock regions, this paper empirically analyzed the relationship between forage product trade and grassland quality and livestock production using cointegration tests and an error correction model. The analysis is based on data on China's forage product imports, grassland comprehensive vegetation cover, and cattle and sheep slaughtering in the seven livestock regions from 2006 to 2020. The following conclusions are drawn:

(1) There is a long-term stable positive equilibrium relationship between forage trade and Chinese grassland quality. This indicates that there is a strong correlation between changes in grassland quality and fluctuations in forage product trade. As an important means to supplement the forage gap, forage trade is likely to enhance the vegetation cover of China's natural grasslands, improve grassland quality, and improve the grassland environment by increasing fodder supply and reducing overgrazing.

(2) There is a long-term stable positive equilibrium relationship between trade in forage products and livestock production in the Qinghai-Tibet Plateau Region, Loess Plateau Region, Southwest Mountain Region, and Northeast Region, respectively. It indicates that livestock production in these regions is more closely related to forage product imports and more susceptible to fluctuations in the amount of forage imports. In contrast, livestock production in the Mengxin Plateau Region, Yellow and Huaihai Sea Region, and East China Sea Region is more affected by other factors and less dependent on externally supplied forage resources.

Based on the above findings, this paper argues that the impact of trade should be fully considered in the improvement of grassland ecology and the development of the livestock industry. The state attaches great importance to grassland protection and has launched many ecological restoration programs since 2000, including the Grain for Green

Project [29], the Three North Shelter Forest Program [30], and the Grassland Ecological Compensation Policy [31], with positive results. At the same time, there is a very close relationship between trade and grassland quality, and fluctuations in the trade of forage products also have an impact on the ecological health of grasslands.

High-quality forage can not only improve the productivity of animal husbandry [32], but also help to adjust the structure of farming and solve the problem of food competition between humans and animals [33]. China's traditional farming is dominated by grain-consuming livestock. Compared with the United States, China is a food-poor country, but its pork production accounts for nearly 50% of the world's supply. The excessive number of grain-consuming livestock is an important reason for the gap in China's grain supply. Related research has shown that if the structure of livestock farming is changed, such as replacing food-consuming livestock with herbivorous livestock and reducing the number of pigs, China's food security problem will be greatly alleviated. In addition, the adjustment of the livestock-breeding structure can also effectively change the current situation of mixed breeds in livestock breeding, where the proportion of high-yielding breeds, such as beef cattle and dairy cows, is small, while the proportion of draft animals is large. Therefore, the trade in forage products, as an important source of high-quality forage supply, is conducive to alleviating the problem of food security in China, adjusting and optimizing the herd structure, adapting to the needs of market competition, improving the overall quality of farming production, and increasing the competitive advantage of the farming industry. Forage trade promotes efficiency in intensive livestock production, and thereby has the potential to increase the proportion of livestock in the total agricultural output [34]. Therefore, the impact of trade on the environment and the livestock industry should be fully considered at the policy-making level.

Although the import of forage products has grown relatively quickly in recent years, the import efficiency and export efficiency of Chinese forage products have shown a downward trend, and there is still room for improving the trade of Chinese grass products [20]. Therefore, it is recommended that:

(1) Multiple measures should be taken to strengthen international cooperation in grass products trade, seek more high-quality trade partners, and promote trade market diversification. Strengthening the existing cooperation and broadening the import channels can ensure the stable supply of high-quality forage grass in China.

(2) China's grass industry should be developed to fill the feed gap from within. Forage trade can fill the gap between the large market demand and small production of forage in China. However, it is externally dependent on and vulnerable to a series of factors, such as price fluctuations, in the international market and changes in the political landscape. Therefore, it is important to strengthen forage trade while also vigorously developing the domestic grass industry, to lay a solid foundation for forage.

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Appendix A

Table A1. Provincial districts included in the livestock geographical regions.

Livestock Geographical Regions	Included Provincial Districts
Qinghai-Tibet Plateau Region	Tibet, Qinghai
Mengxin Plateau Region	Inner Mongolia, Gansu, Xinjiang
Loess Plateau Region	Shanxi, Shaanxi, Ningxia
Southwest Mountain Region	Chongqing, Sichuan, Guizhou, Yunnan
Northeast Region	Liaoning, Jilin, Heilongjiang
Yellow and Huaihai Sea Region	Beijing, Tianjin, Hebei, Shandong, Henan
East China Sea Region	Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Hainan

Table A2. Results of the unit root test of the variables.

Variables	(*c*,*t*,*p*)	ADF Statistics	1% Critical Value	5% Critical Value	10% Critical Value	Conclusion
$lnFPI_t$	(c, t, 3)	−1.899	−4.380	−3.600	−3.240	Non-stationary
$d.lnFPI_t$	(c, t, 3)	−6.753 ***	−4.380	−3.600	−3.240	Stationary
$lnVC_t$	(c, t, 0)	−1.332	−4.380	−3.600	−3.240	Non-stationary
$d.lnVC_t$	(0, 0, 0)	−2.018 **	−2.660	−1.950	−1.600	Stationary
$lnCSS_t$	(c, t, 0)	−1.361	−4.380	−3.600	−3.240	Non-stationary
$d.lnCSS_t$	(0, 0, 0)	−2.050 **	−2.660	−1.950	−1.600	Stationary
$lnCSS1_t$	(c, 0, 0)	−2.281	−3.750	−3.000	−2.630	Non-stationary
$d.lnCSS1_t$	(0, 0, 0)	−4.059 ***	−2.660	−1.950	−1.600	Stationary
$lnCSS2_t$	(c, t, 0)	−2.607	−4.380	−3.600	−3.240	Non-stationary
$d.lnCSS2_t$	(c, 0, 0)	−4.787 ***	−3.750	−3.000	−2.630	Stationary
$lnCSS3_t$	(c, t, 0)	−1.277	−4.380	−3.600	−3.240	Non-stationary
$d.lnCSS3_t$	(0, 0, 0)	−2.632 **	−2.660	−1.950	−1.600	Stationary
$lnCSS4_t$	(c, t, 3)	−2.190	−4.380	−3.600	−3.240	Non-stationary
$d.lnCSS4_t$	(0, 0, 0)	−1.710 *	−2.660	−1.950	−1.600	Stationary
$lnCSS5_t$	(c, 0, 0)	−2.386	−3.750	−3.000	−2.630	Non-stationary
$d.lnCSS5_t$	(c, 0, 1)	−5.334 ***	−3.750	−3.000	−2.630	Stationary
$lnCSS6_t$	(c, 0, 5)	−6.032 ***	−3.750	−3.000	−2.630	Stationary
$d.lnCSS6_t$	(0, 0, 5)	−4.345 ***	−2.660	−1.950	−1.600	Stationary
$lnCSS7_t$	(c, t, 0)	−1.299	−4.380	−3.600	−3.240	Non-stationary
$d.lnCSS7_t$	(c, 0, 0)	−3.378 **	−3.750	−3.000	−2.630	Stationary

Note: *** denotes a 1% significance level, ** denotes a 5% significance level, and * denotes a 10% significance level; c, t, p denote the drift term, time trend term, and lag order, where 0 denotes no corresponding term; $d.$ denotes a first-order difference. Same below.

Table A3. Results of the ordinary least squares estimation of the coefficient of cointegration.

Equation
$lnVC_t = 3.837443 + 0.0330532\ lnFPI_t$
$lnCSS_t = 10.23602 + 0.0391309\ lnFPI_t$
$lnCSS1_t = 7.126315 + 0.0191151\ lnFPI_t$
$lnCSS2_t = 9.050992 + 0.0619547\ lnFPI_t$
$lnCSS3_t = 7.065525 + 0.1001098\ lnFPI_t$
$lnCSS4_t = 7.902654 + 0.0869083\ lnFPI_t$
$lnCSS5_t = 7.739439 + 0.0117449\ lnFPI_t$
$lnCSS7_t = 8.197014 + 0.0449347\ lnFPI_t$

Table A4. Results of the unit root test for residuals.

Variables	(c,t,p)	ADF Statistics	1% Critical Value	5% Critical Value	10% Critical Value	Conclusion
R_VC_t	$(0,0,1)$	−3.769 **	−3.96	−3.41	−3.12	Stationary
R_CSS_t	$(0,0,2)$	−2.800	−3.96	−3.41	−3.12	Non-stationary
R_CSS1_t	$(0,0,2)$	−3.588 **	−3.96	−3.41	−3.12	Stationary
R_CSS2_t	$(0,0,2)$	−2.022	−3.96	−3.41	−3.12	Non-stationary
R_CSS3_t	$(0,0,2)$	−3.424 **	−3.96	−3.41	−3.12	Stationary
R_CSS4_t	$(0,0,5)$	−4.283 ***	−3.96	−3.41	−3.12	Stationary
R_CSS5_t	$(0,0,0)$	−4.529 ***	−3.96	−3.41	−3.12	Stationary
R_CSS7_t	$(0,0,2)$	−2.154	−3.96	−3.41	−3.12	Non-stationary

Note: *** denotes a 1% significance level, ** denotes a 5% significance level.

Table A5. Results of the Granger causality test.

Original Hypothesis	F-Statistic	*p*-Value	Whether to Reject the Original Hypothesis
$lnFPI_t$ is not the Granger reason for $lnVC_t$	39.824	0.0001	Reject
$lnVC_t$ is not the Granger reason for $lnFPI_t$	0.34413	0.7188	No Reject
$lnFPI_t$ is not the Granger reason for $lnCSS1_t$	7.6219	0.0259	Reject
$lnCSS1_t$ is not the Granger reason for $lnFPI_t$	0.81815	0.5369	No Reject
$lnFPI_t$ is not the Granger reason for $lnCSS3_t$	6.0755	0.0403	Reject
$lnCSS3_t$ is not the Granger reason for $lnFPI_t$	6.6013	0.0344	Reject
$lnFPI_t$ is not the Granger reason for $lnCSS4_t$	0.6074	0.5422	No Reject
$lnCSS4_t$ is not the Granger reason for $lnFPI_t$	0.15675	0.6997	No Reject
$lnFPI_t$ is not the Granger reason for $lnCSS5_t$	8.3216	0.0111	Reject
$lnCSS5_t$ is not the Granger reason for $lnFPI_t$	10.443	0.0059	Reject

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