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EDITED BY
Denise Adelaide Gomes Elejalde,
Universidade Tecnológica Federal do Paraná
Pato Branco, Brazil

REVIEWED BY
Stefan Tangermann,
University of Göttingen, Germany
Corrado Ievoli,
University of Molise, Italy

*CORRESPONDENCE
Xiaoxia Dong
✉ dongxiaoxia@caas.cn

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Sustainable market? The impact of downstream market concentration on high-quality agricultural development: evidence from China's dairy industry

Zetian Yu[1], Guang Feng[2], Hao Liu[1], Hua Peng[1] and Xiaoxia Dong[1]*

[1]Agricultural Information Institute, Chinese Academy of Agricultural Sciences, Beijing, China, [2]Zibo Agricultural Science Research Institute, Zibo, China

The downstream concentration of agricultural products markets under the asymmetric competition pattern of the supply chain has a profound impact on upstream agricultural production. Is this centralized market structure sustainable and efficient? The study examines the effects and mechanisms of agricultural product downstream concentration on the high-quality development of agriculture using the dairy industry as an example. Panel data from 10 provinces in China from 2004 to 2021 were selected for analysis. Using Malmquist index, fixed effects model and other methods, the research results prove that: (1) Downstream dairy market concentration is unfavorable to upstream raw milk total factor productivity growth. However, there is scale heterogeneity in this negative effect, with a positive impact for small-scale farming and a negative impact on medium-scale and large-scale farming. (2) Downstream market concentration drives upstream raw milk total factor productivity growth through technical efficiency improvements and market demand expansion, but it also inhibits raw milk total factor productivity growth through mechanisms that squeeze production margins and impede technological progress. Negative mechanisms are the main effect. (3) Higher wages, higher raw milk prices and an improved ratio of concentrate to crude are all helping to mitigate the negative effects of downstream concentration to some extent, but net profit retention and a high proportion of fixed assets will further exacerbate the negative effects. To better address the challenges brought by the trend of downstream market concentration and promote high-quality agricultural development, this paper proposes three suggestions: enhancing the market position of dairy farmers, regulating monopolistic behavior of oligopolies, and building a mechanism for linking interests.

KEYWORDS

downstream market concentration, asymmetric competition, raw milk, high-quality agriculture, total factor productivity

1 Introduction

In a free market, oligopolistic market structures are widespread and consumers are accustomed to choosing products offered by a few large companies (Head and Spencer, 2017). Since the new century, with the deep development of China's market economy, the highly concentrated market structure model gradually becomes widespread driven by the effect of economies of scale. This trend is also emerging in the agro-processing market, especially in dairy sector, which has caused extensive concern and worry (He et al., 2013). Unfortunately, the issue of agricultural monopolies is relatively little discussed in the academic field. This may be related to the China's particular realities of agricultural production. On the one hand, Chinese agricultural production has long been characterized by small-scale farming. Agricultural production entities are numerous and geographically dispersed. Its degree of market concentration and monopoly lags significantly behind that of other industries. On the other hand, agricultural products, as the necessary materials for people's life, have the function of basic security. Agricultural monopolistic behaviors are more strictly prevented and regulated by the government, which has reduced people's concerns about its harmful effects. But from the perspective of market characteristics, the agricultural products market has gradually matured and its marketization attribute has been continuously strengthened in recent years. With the comprehensive promotion of the scaling-up of the agricultural products processing industry, the trend of centralization has been strengthening. The pattern of asymmetric competition in the upstream and downstream in agriculture has also gradually formed, which has a profound impact on agricultural production.

There are many categories of agricultural products and the intensity of upstream and downstream asymmetric competition varies from category to category. This research uses the dairy industry as an example to explore the impact of the downstream market concentration (DMC) on upstream agricultural production (UAP). First, the dairy industry occupies an important position in agriculture and even the entire national economy. In 2017, the government's "Central Document No. 1" put forward "comprehensive revitalization of the dairy industry." In 2018, the government issued the Opinions on Promoting the Revitalization of the Dairy Industry and Guaranteeing the Quality and Safety of Dairy Products and Several Opinions on Further Promoting the Revitalization of the Dairy Industry. In 2021, the "Central Document No. 1" once again proposed to continue to implement the revitalization of the dairy industry. All the above reflects the great importance that the state attaches to the development of the dairy industry.

In addition, in answering the question of "The impact of downstream market concentration on upstream agricultural production," the dairy industry is the most typical and representative. From the perspective of the supply chain, milk production, processing and consumption constitute a complete supply chain. Under normal circumstances, each link of the chain should maintain an equal market position and a reasonable benefit distribution mechanism. However, China's dairy industry formed a unique development pattern of "vertical integration with dairy enterprises as the core." In this development pattern, along with a highly centralized market structure, the processing link is in a dominant position in the whole supply chain. This leads to unfair distribution of benefits and the interests of dairy farmers are seriously threatened. The efficiency of raw milk production and international competitiveness are also negatively affected (Ma et al., 2018; Yu et al., 2023). In conclusion, the importance and typicality of the dairy industry make it very representative in the study of "downstream market concentration and agricultural production," which can provide an effective reference for the future conflict of downstream concentration and agricultural production in other agricultural products market.

Existing research indicates that the increase of total factor productivity (TFP) is the main driver for substantial agricultural development in China (Sheng et al., 2020). Under the new situation of constraints on production factors and environmental carrying capacity, it is imperative to increase TFP to achieve high-quality agricultural development (Xu et al., 2023). High-quality agricultural development not only focuses on increasing production but also emphasizes comprehensive, coordinated, and sustainable agricultural development. High-quality agricultural development aims to improve the total factor productivity of agricultural production through technological innovation, agricultural mechanization, and efficient agricultural management, thereby achieving greater output per unit area, per unit of labor, and per unit of input. Therefore, this paper argues that TFP in agriculture is the best evidence for evaluating the goodness of agricultural production and the degree of high-quality development of agriculture. In summary, this paper explores the impact and mechanism of downstream dairy market concentration on raw milk TFP growth, so as to provide a new perspective for deepening the cognition of the trend of agricultural market concentration and promoting the high-quality development of agriculture.

The remainder is organized as follows: the second is the literature review and theoretical hypotheses; the third is the empirical methodology, variable setting and data description; the fourth is the analysis of the empirical results; and finally, the conclusion and policy recommendations are provided.

2 Literature review and theoretical hypotheses

2.1 Literature review

How to improve TFP to achieve high-quality development of agriculture has always been a hot issue in the academic community (Jin et al., 2002). Many scholars have explored "How to enhance the TFP of agriculture." The optimization paths obtained can be broadly divided into two categories. One category is internal adjustment and allocation optimization of agricultural production factors, such as improving factor quality (Foster et al., 2008), adjusting resource mismatch and factor distortion (Hsieh and Klenow, 2009; Ayerst et al., 2020) and so on. The other category is to improve the external environment of agriculture, such as natural conditions (Villavicencio et al., 2013; Kunimitsu et al., 2016), policy support (Srinivasan and Jha, 2001), infrastructure (Hulten et al., 2006), R&D investment (Fan and Pardey, 1997; Fan, 2000; Gong, 2020) and so on.

With the development of supply chain integration, more and more scholars have begun to pay attention to the impact of market concentration characteristics on TFP upstream and downstream. But unfortunately, the relevant research in the field of agriculture is still relatively rare. The impact of market concentration on TFP can be simply divided into two categories, i.e., the structural-efficiency relationship under the same link and the non-same link. The relationship between market structure and efficiency in the same link of the supply chain can be categorized into two schools of thought, "market power hypothesis" and "efficiency structure hypothesis," both of which have a wide range of supporters in the field of economic theory and empirical evidence (Berger and Hannan, 1998).

The mainstream view of the "market power hypothesis" is that oligopolistic corporations use their market position to manipulate prices and crowd out competitors through conspiracy and other means, thereby capturing high profits and promoting the efficiency of market players (Rhoades, 1985; Lee et al., 1998). However, some scholars believed that oligopolies unilaterally utilized their own market position to obtain high profits and thus market share at the micro level is the optimal indicator of market dominance, so there may not be a significant correlation between market concentration and market performance (Berger and Hannan, 1998). Some scholars have argued that oligarchic corporations lack incentives to reduce costs and increase efficiency, therefore a rise in market concentration would not encourage the development of efficiency but rather impede the industry's advancement (Gavurova et al., 2017). Furthermore, some experts proposed that the relationship between market structure and performance was "inverted U-shaped" rather than monotonic, with excessive or insufficient market concentration having a negative impact on performance (Mansfield, 1962). The logic of the "efficient structure hypothesis" is the opposite of the "market power hypothesis," which holds that market structure is not a cause but a consequence. It is the increasing level of efficiency of oligopolistic market players, through scale effects and advanced technological and managerial advantages, that leads to the acquisition of a larger market share and increased market concentration (Greene and Segal, 2004; Park and Weber, 2006).

The relationship between market concentration and efficiency under the non-same links of the supply chains has not yet reached a consensus in the academic community. And related research mainly focused on the impact of upstream monopoly on the efficiency of the downstream. At present, China's product market in the downstream has basically realized free competition, while the upstream market still maintains a state-owned monopoly, which formed asymmetric competition among firms of different ownership (Liu and Shi, 2011; Li et al., 2015). Scholars have different views on the impact of upstream monopolization under such asymmetric competition. Liu and Shi (2011) argued that the upstream monopoly of state-owned enterprises not only led to higher production costs in the upstream industry, but also affects downstream product prices through upstream and downstream linkages, thus reducing the efficiency of downstream firms and the overall social welfare. Wang and Shi (2014) confirmed that the upstream monopoly formed by government protection was not conducive to the quality upgrading of downstream products, and this negative effect would be further exacerbated with the widening of the competitive gap between the upstream and downstream markets (Wang and Shi, 2014). A few studies have also examined the hazards of upstream monopolies from the perspectives of downstream costs, R&D and innovation investment, benefit distribution and resource allocation (Zhang et al., 2001; Brandt et al., 2008; Du et al., 2014). However, some scholars believed that the increase of upstream concentration helped to exert the scale effect and technology agglomeration effect, which in turn improved the quality of intermediates and the ability of downstream firms to assimilate and utilize the technology, and thus enhanced the efficiency of the downstream market (Smythe and Zhao, 2006; Kugler and Verhoogen, 2012). Wang (2017) argued that the impact of monopoly under asymmetric competition could not be generalized. The nature of monopoly should be analyzed first. Rent-seeking monopoly was indeed detrimental to the growth of industry TFP, but innovative monopoly was not. It could not only significantly increase the enterprise's own TFP, but also increase the TFP of the same industry and related industries through the spillover effect (Wang, 2017). Tan and Zhang (2022) also argued that upstream monopoly had both positive and negative impacts on downstream markets. The positive impact lay in the fact that the upstream monopoly forced the downstream to improve the efficiency and profitability for counteracting the upstream pressure. The negative effect lay in the fact that upstream monopolization limited firms' innovation by increasing the share of intermediate inputs and reducing firms' endogenous cash flows (Tan and Zhang, 2022).

There are relatively few studies about the impact of downstream monopolies on upstream. Lommerud et al. (2005) found that downstream firms' mergers squeezed the profits of upstream firms. Zhu et al. (2016) extended the bi-oligopoly structure to a multi-oligopoly theoretical analytical framework and found that the conclusion still held. Spulber (2013) and De Bettignies et al. (2018) argued that monopolistic downstream industries were not conducive to innovation by upstream firms. Expected returns to R&D and technology licensing revenues for upstream firms decreased as the degree of downstream monopoly increased. Chen (2004) and Shahrur et al. (2005) argued that downstream monopolization had a dampening effect on upstream firms' revenue and innovation through downward pressure on product prices and diversity inhibition constraints. However, some studies found that downstream oligopoly power could reverse incentivize upstream firms to innovate their processes to reduce production costs (Inderst and Wey, 2007).

2.2 Theoretical hypotheses

The existing literature provides an important foundation for the conduct of this study. However, related research mainly focused on monopoly market participants themselves and their efficiency loss to other participants in the same industry, but largely ignored its role on upstream producers. Relevant literature in the field of agriculture is still slightly insufficient. The relationship and the mechanisms between downstream market concentration of agricultural products and upstream agricultural production are still poorly understood. Based on the literature review and typical facts of the dairy industry, this part tries to put forward reliable theoretical hypotheses to lay the foundation for the empirical research in the later part.

Since China's reform and opening-up, the raw milk market in China has been overly competitive, characterized by numerous participants, small scale, decentralized distribution and low market share. Despite the rapid acceleration of the scaling-up process after 2008, the current raw milk market still lacks clear centralized characteristics (Lu et al., 2009). Conversely, with the rapid development of China's economy and the intensification of globalized competition, the processing sector of the dairy industry experiences a quick acceleration of mergers and expansion because of scale of efficiency and policy support. In 2023, the total market share of Mengniu and Yili has exceeded 40%, and the total share of the top four and eight have been more than 50 and 60%, respectively. The concentration of China's dairy market is rising, characterized by a duopoly (Wu et al., 2018; Yu et al., 2023).

China's dairy farming costs are high, facing the competition of low-priced milk powder from abroad for a long time, so dairy farmers are in a weak position in the raw milk trading market. Under the oligopoly trend of long-term increase in downstream dairy market concentration, the negotiating position of dairy farmers has become even more marginal, who are now purely "price takers." When the market moves up and earnings increase, downstream dairy companies and their retailers share the lion's share of profits, with limited growth of dairy farmers' earnings. When the market is in the doldrums and encounters external shocks, dairy companies utilize their dominant market position to compress the profit margins of dairy farmers and transfer business risks by controlling prices and limited purchases (Mo et al., 2012). The serious consequences of this downstream industry repression could be seen in "milk scandal" in 2008[1] and "dumping milk and killing cows" [2] incident in late 2014. On the one hand, this trend of concentration has further strengthened the dairy industry's pattern of "supply chains with dairy enterprises as the core" and the problem of unbalanced distribution of benefits in the industry chain has further intensified. The interests of dairy farmers were jeopardized and incidents of "dumping and killing of cows" frequently occur, which seriously affects the efficiency level and sustainable development of dairy farming. On the other hand, to counter this downstream suppression, dairy farmers may take desperate measures such as cutting corners, adding illegal chemicals, and so on. These will pose a fatal threat to the long-term development of the overall industry (Jia and Huang, 2011; Wu et al., 2018).

Although dairy farming is negatively constrained by downstream market concentration, different scales of farming may not be affected differently. In terms of counterbalance ability, medium- and large-scale farms have a high output level and a constant supply of milk. Therefore, they enjoy a certain bargaining power in the negotiation with dairy enterprises, who have a stronger counterbalance ability. The small-scale farms are in a more vulnerable negotiating position due to scattered distribution, small milk production and inconvenient acquisition. In terms of exiting mechanisms, small-scale farms exit costs are minor whereas medium- and large-scale exit costs are substantial. Under the pressure of rising downstream market concentration year by year, many small-scale farms have been forced to exit the market. Most of these exits are less efficient, so the rising downstream market concentration indirectly fulfills the function of market elimination and pushes the growth of raw milk TFP of small-scale farming. Medium and large-scale farming compared to small-scale in the ability of counterbalance slightly stronger, but this counterbalance in the face of dairy companies is insignificant. Moreover, medium- and large-scale farmers will not easily exit the market. Therefore, the downstream market concentration increases on the production efficiency of medium and large-scale farming will still be a negative impact. In short, the concentration of downstream markets should hinder the growth of production efficiency in small, medium, and large-scale farms, and have a stronger hindering effect on small-scale farms. However, the concentration of downstream markets has greatly accelerated the market exit of small-scale inefficient farms. Therefore, from a macro perspective, the concentration of downstream markets is highly likely to promote the efficiency improvement of small-scale farms groups. Based on the above discussion, this paper proposes hypothesis H1.

> H1: Downstream dairy market concentration has a negative impact on upstream raw milk TFP growth and there is heterogeneity according to farming scale.

The impact of monopoly is no single, but may both positive and negative. Positive and negative mechanisms may coexist in the impact of downstream dairy market concentration on upstream raw milk TFP growth. In terms of positive mechanisms, Schumpeter's theory of innovation suggests that oligopoly is conducive to innovation. Rising concentration in the dairy market drives managerial and technological advances, and the theory of technology diffusion suggests that such advanced managerial and technological innovations have a spillover effect that leads to the development of the raw milk production. As the concentration of the dairy market continues to increase, oligopoly characteristics become more pronounced. Oligopolistic dairy companies will be more inclined to establish modern organizations with more scientific management, and the efficiency of dairy products processing will increase significantly. Raw milk production and dairy processing are the upstream and downstream links of the same industry chain. Under the spillover effect, dairy farmers can learn advanced management experience and organizational pattern to be quickly applied to the construction of modern farms. In addition, when a dairy company establishes a stable contractual relationship with a dairy farm, it will regulate the production process and quality standards of raw milk, forcing dairy farms to improve its production process and management system. In some dairy farms in which dairy companies have invested, acquired a controlling stake or established by themselves, there may even be management specialists assigned by the dairy companies, in which case the spillover effect is even more pronounced. In addition, the oligopoly dairy companies are willing to organize technical training sessions, lectures for dairy farmers. These measures are conducive to the better development of farms. In summary, increased downstream market concentration will improve dairy farming TFP growth through management innovation spillovers.

1 In September 2008, many infants who consumed infant milk powder produced by the Sanlu Group were found to be suffering from kidney stones, and the chemical melamine was found in their milk powder. Subsequent sampling by the AQSIQ showed that melamine was found in liquid milk, including in some well-known dairy companies. The incident triggered a serious social crisis and was characterized as a "major food safety incident." The development of China's dairy industry entered an ice age and has not yet escaped its impact (Xin and Stone, 2008; Qian et al., 2010).

2 "Dumping milk and killing cows" incidents have occurred dozens of times since 2003, with the outbreak in late 2014 being one of the larger ones. Since August 2014, numerous incidents of "cow dumping and killing cows "broken out in Shandong, Qinghai, Hebei, Guangdong, and other places, because of dairy companies purchasing raw milk at below-cost prices. Retailers and farming communities suffered serious losses in the storm, while large farms, which have a stronger voice in comparison, were hardly affected. Recently, there have been reports of "killing cows by dumping milk."

We also note that the oligopolistic structure of the dairy market has a positive effect on expanding the dairy market. On the one hand, the rise of oligopolistic dairy enterprises has significantly enhanced the international competitiveness of domestically produced dairy products and reduced the dumping of foreign dairy products on the domestic market. On the other hand, the oligopoly dairy enterprises spend a huge amount of marketing costs to promote the high nutritional value of milk and call for healthy diets. These actions have effectively driven the expansion of the overall market, thus creating development space for domestic dairy farmers. In highly competitive markets, it is evident that no enterprise has the energy to consider expanding the market space of the entire industry. In summary, the increase of downstream market concentration can create development space for raw milk production by resisting foreign dairy dumping and tapping market consumption potential, thus promoting raw milk TFP growth.

In terms of negative mechanisms, most current research has concluded that the impact of increased upstream monopolization trends on downstream production was mainly negative. The mechanism is that monopolies capture excess profits through depressed pricing, which leads to difficulties in guaranteeing product quality, suppression of variety diversity and insufficient investment in innovation resources, thus weakening TFP growth (Spulber, 2013; De Bettignies et al., 2018). The growth of concentration in the dairy market has intensified asymmetric competition upstream and downstream. Dairy companies squeeze the profitability of dairy farms and transfer business risks through the dual means of controlling prices and volume of purchases. This has resulted in chronically low levels of profitability in dairy farming and an inability to resource invest for TFP growth. In summary, increased downstream market concentration weakens dairy TFP growth by squeezing production margins.

Another issue that needs to be discussed is the role played by technological advances in downstream concentration trends. Numerous articles have confirmed that technological change is beneficial for TFP growth (Chen et al., 2020; Li et al., 2021; Peypoch et al., 2021). Some viewpoints believe that the concentration of downstream markets is conducive to promoting downstream technological progress. According to the theory of technological diffusion, downstream technological progress may drive upstream technological progress, thereby driving TFP growth. However, it is worth noting that unlike the spillover effects of management innovation, the spillover effects of technological innovation are weak. On the one hand, dairy processing technology and dairy farming technology are two completely different types of technology, so the impact of technology diffusion effects is limited. Technological change is largely decided in the upstream sectors of agriculture. It is there that technological paradigms are decided that result in the innovations that the farm is to some extent "persuaded" to adopt. On the other hand, the diffusion of managerial innovations is usually open and costless, but the diffusion of technological innovations is usually more conservative and oligopolistic. Dairy firms even will try to prevent the diffusion of technology. The main technological diffusion effects are found only in the more vertically integrated holdings and self-built farms. So, while downstream concentration does drive technological advances in dairy farming to some extent, the impact is very weak.

Because of the low profitability of dairy farming due to downstream concentration and market instability, as well as farms' insufficient expectations of advanced technology and limited resources, the concentration of downstream markets hinders investment in advanced technology for farms. In summary, downstream market concentration inhibits TFP growth by impeding technological progress.

Based on the above analysis, this paper proposes hypotheses H2, H2a, and H2b.

> H2: There are both positive and negative mechanisms in the impact of downstream market concentration on upstream raw milk TFP growth, with the negative mechanism being the main effect.
>
> H2a: Downstream market concentration drives upstream raw milk TFP growth through mechanisms of technological efficiency improvement and market demand expansion.
>
> H2b: Downstream market concentration inhibits upstream raw milk TFP growth through mechanisms of squeezing production margins and impeding technological progress.

3 Empirical method, variables setting, and data description

3.1 Empirical method

3.1.1 Modeling to measure and decompose raw milk TFP growth

Assume that (x_{t+1}, y_{t+1}) and (x_t, y_t) denote the inputs and outputs in period t + 1 and period t, respectively; d_0^t, d_0^{t+1} denote the distance functions in period t and period t + 1 with reference to the technology T^t in period t, respectively. The Malmquist indices M_0^t, M_0^{t+1} with reference to the technology T^t, T^{t+1} in periods t and t + 1, respectively, can be expressed as follows:

$$M_0^t = \frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)} \tag{1}$$

$$M_0^{t+1} = \frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_t, y_t)} \tag{2}$$

Data envelopment analysis (DEA) can be used to calculate the distance function in the above Equation 2 (Färe et al., 1994). The geometric mean of the two can be used as the Malmquist index $M_0^{t,t+1}$ which measures the change in productivity from period t to period t + 1

$$M_0^{t,t+1} = \left| M_0^t * M_0^{t+1} \right|^{\frac{1}{2}} = \left| \frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)} * \frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_t, y_t)} \right|^{\frac{1}{2}} \tag{3}$$

Malmquist index can be decomposed into the technical efficiency change index and technological change index, as follows:

$$M_C^{t,t+1} = \frac{d_c^{t+1}\left(x_{t+1},y_{t+1}\right)}{d_c^{t}\left(x_t,y_t\right)} * \left| \frac{d_c^{t}\left(x_{t+1},y_{t+1}\right)}{d_c^{t+1}\left(x_{t+1},y_{t+1}|C\right)} * \frac{d_c^{t}\left(x_{t+1},y_{t+1}\right)}{d_c^{t+1}\left(x_t,y_t\right)} \right|^{\frac{1}{2}} \quad (4)$$

where, the first item represents the change of technical efficiency; the second item represents the technological change.

Compared to other TFP growth measurement methods, the Malmquist index based on DEA does not require additional prior assumptions, provides detailed analysis of productivity changes, supports panel data and multiple input and output indicators, which is one of the most widely used efficiency measurement methods. Its disadvantage is that it does not take into account random shocks, so stochastic frontier analysis (SFA) will be used for compensation in subsequent robustness tests.

3.1.2 Two-way fixed effects model

Define the variable TFPC to represent TFP growth. TFP growth represents the change of total factor productivity in two neighboring years, that is, $TFPC_t$ represents the growth of TFP from year t-1 to year t. Therefore, the explanatory variables are relatively lagged by one period when setting up the regression model, i.e., the explanatory variable in year t corresponds to the growth of TFP from year t to year t + 1. The regression model is set up as follows:

$$TFPC_{i(t+1)} = \beta_0 + \beta_1 str_{it} + \beta_2 Z_{it} + \varepsilon_{it} \quad (5)$$

where $TFPC_{i(t+1)}$ is the explained variable, representing the TFP growth from period t to t + 1 in province i; str_{it} is the core explanatory variable, representing changes in the concentration of downstream market; Z_{it} is the control variable; ε_{it} is the residual term; $\beta_0$is a constant term; β_1 is the marginal effect of downstream dairy market concentration on raw milk TFP growth; β_2 is the to-be-estimated coefficients of the control variables.

Raw milk TFP growth may also be affected by province-specific factors that do not change over time, such as soil and pasture quality, and time-varying factors such as policy adjustments and climate change. To accurately estimate the impact of changes in downstream market concentration on raw milk TFP growth, this paper controls for regional fixed effects λ_i at the province level and time fixed effects η_t at the year level using a two-way fixed effects model as follows:

$$TFPC_{i(t+1)} = \beta_0 + \beta_1 str_{it} + \beta_2 Z_{it} + \lambda_i + \eta_t + \varepsilon_{it} \quad (6)$$

To ensure the robustness of the empirical results, the paper will follow up with two-way fixed effects-panel Tobit model and stochastic frontier production function "one-step" regression model instead of two-way fixed effects-panel regression model to carry out further tests.

3.2 Variables settings

3.2.1 Explained variable

The high-quality development of agriculture not only focuses on the improvement of yield, but also emphasizes the development of "innovation, coordination, green, openness, and sharing" in agriculture. Existing research has used comprehensive evaluation methods to measure the level of high-quality development, such as the entropy method and projection tracking model (Cui et al., 2022; Lu et al., 2022). While more literature uses total factor productivity to characterize the high-quality development of agriculture (Du et al., 2022; Lin et al., 2022; Wang et al., 2022). This paper uses TFP to measure the level of high-quality development of dairy farming.

Setting appropriate input and output variables is the prerequisite for measuring TFP growth and the basis for conducting this paper. Referring to the mature practices of existing studies (Ma et al., 2012; Liu et al., 2022; Yu et al., 2023), milk yield (main product production per cow) is chosen as the output variable. For the selection of input variables, this paper measures labor inputs by the number of laborers per cow (including family labor and hired labor). Depreciation cost of fixed assets is used to measure capital inputs. Concentrate feed cost, roughage cost[3] and other costs (including direct costs such as feed processing costs, water costs, fuel and power costs, medical prevention and vaccination costs, death loss costs, technical service costs, tools and materials, repair and maintenance and other direct costs, as well as indirect costs such as insurance premiums, management costs, financial costs, and marketing costs) are included in intermediate inputs.[4]

To eliminate the bias effect of price inflation on efficiency measurement, this study sets 2003 as the base year. It adjusts concentrate feed expenses and roughage feed expenses using the "feed price index" from the "price index of agricultural means of production." It adjusts depreciation of fixed assets and intermediate costs using the "price index of agricultural means of production ".

3.2.2 Core explanatory variables

The Herfindahl–Hirschman Index (HHI) and the industry concentration index (CR) are used by the great majority of empirical research currently in existence to assess market concentration. The CR index performs well in measuring the influence of leading firms on market structure, clearly depicting the concentration of market power in the industry. However, it overlooks the scale distribution of other firms, the relative situation among leading firms and changes in market share and product differentiation levels. In contrast, the HHI index can effectively address this limitation. It measures market concentration by summing the squares of the market shares of all firms in the industry, which not only reflects the relative differences in the size of market players more realistically, but is also more sensitive to changes in the market share of the largest few firms in the industry. Therefore, this study selects the HHI index as the standard for evaluating the concentration of the dairy product market. The formula is as follows:

$$HHI = \sum_{i=1}^{N} \left(\frac{X_i}{X} \right)^2 * 10000 \quad (7)$$

3 Referring to related studies, feed inputs are subdivided into concentrate feed inputs and roughage inputs to better explore the input–output relationship and the path of efficiency improvement.

4 In dairy farming, land cost expenditure usually accounts for <1%, which is small and usually ignored (Liu et al., 2022; Yu et al., 2023).

TABLE 1 Descriptive statistics of variables.

Category and name of variables	Variable symbols	Assignment method	Mean value	Standard deviation	Maximum value	Minimum value
Explained variable						
Total factor productivity growth	TFPC	Malmquist productivity index	1.014	0.079	1.255	0.725
Core explanatory variable						
The Herfindahl–Hirschman index	HHI	Equation 7	623.733	180.853	1015.169	284.868
Control variables						
Stocking scale	SCALE	Average number of cows kept	199.811	355.237	1494.100	3.253
Wage level	WAGES	Unit worker cost/number of workers	65.018	28.630	124.286	16.730
Profit level	PROFIT	Profit/total cost	32.165	14.959	92.202	2.213
Raw milk price	PRICE	Raw milk purchase price	157.938	43.276	335.003	78.715
Concentrate to roughage ratio	CTR	Concentrate cost/roughage cost	2.562	0.866	6.546	1.448
Health and epidemic prevention expenditure	HAE	Health and epidemic prevention costs/ total costs	1.247	0.578	3.184	0.474
Fixed asset investment	FAI	Depreciation of fixed assets/total cost	12.361	1.826	17.858	8.489

where X_i denotes the market sales of dairy firm i; X denotes the total market sales.

Considering the actual situation of dairy companies' data disclosure, it is unrealistic to sort out the business data of all dairy enterprises. Therefore, this paper selects the top 10 market shares as the main measurement objects, and then assigns the remaining market shares to other enterprises using the mean value method. Since the market share of the top 10 dairy enterprises is very large and the market share of other enterprises is very low, under the "amplification effect" of the square (Tang, 2009), it will not have a large bias effect on the measurement of market concentration. To ensure the robustness of the results, this paper will use the CR index mentioned above, as well as the Gini coefficient and entropy index to replace the HHI index for further testing.

3.2.3 Control variables

To identify causal effects more accurately, it is also necessary to set control variables that may have an impact on raw milk TFP growth. Referring to related studies (Barnes, 2006; Ma et al., 2012; Sauer and Latacz-Lohmann, 2015; Njuki et al., 2020; Liu et al., 2022; Yu et al., 2023), the control variables selected are as follows: stocking scale, wage level, profit level, raw milk price, roughage to concentrate ratio, health and epidemic prevention expenditure and fixed asset investment. In related studies, the factors affecting TFP growth of raw milk are far more than that and there are three main considerations for selecting the above variables in this paper. First, some indicators may not differ significantly across provinces and years, for example the industrialized dairy farming and inter-provincial circulation of forage grass makes the impact of soil quality (Latruffe et al., 2004) on TFP growth in dairy farming extremely limited. Indicators of the degree of downstream integration derived from country-specific studies (Latruffe, 2004) are also not applicable to inter-provincial studies. Factors such as the average age of dairy farm workers, access to information and breeds in each province are similarly considered. Secondly, some variables are less commonly used in China, such as the degree of multifunctionality, precision agriculture technology and cow welfare (Barnes, 2006). Third, certain variables are more difficult to measure at the provincial level, such as farming experience, training frequency, agricultural knowledge and innovation system (AKIS). To avoid omission of variables, this paper sets up both area fixed effect variables and time fixed effect variables to measure other effective variables that may exist.

3.3 Data sources

Based on data availability and sample representativeness, this paper selects nine provinces, including Inner Mongolia, Heilongjiang, Xinjiang, Shanxi, Shandong, Yunnan, Liaoning, Henan and Fujian, and "average"[5] from 2004 to 2021 as the research object of this paper. Specifically, the data of input–output index is from 2004 to 2021 "National Compendium of Agricultural Products Cost and Benefit Information," which is obtained from the average of four scales of dairy farming data. The deflators "Feed Price Index" and "Agricultural Production Material Price Index" are obtained from the China National Bureau of Statistics (NBS). The core explanatory variables and their robustness test variables are obtained from the statistics of annual reports of listed companies, China Dairy Statistics and China Dairy Statistics Yearbook from 2004 to 2021. The data of control variables are obtained from 2004 to 2021 Compilation of National Agricultural Product Cost and Profit Data and the 2004–2021 Statistical Yearbook of China's Dairy Industry. Based on the above sources, this study collected and formed long-term panel data from 10 regions over the past 18 years. The basic statistical characteristics of the indicators are shown in Table 1.

5 The "average" is the average of the data for all provinces, including unselected provinces. It is a new decision unit that represents the national average across provinces. The addition of "average" enhances the accuracy of the efficiency measure. In addition, it can also be used as an indicator of the national average to extract more effective information. In the following, the 10 samples are referred to as "10 provinces."

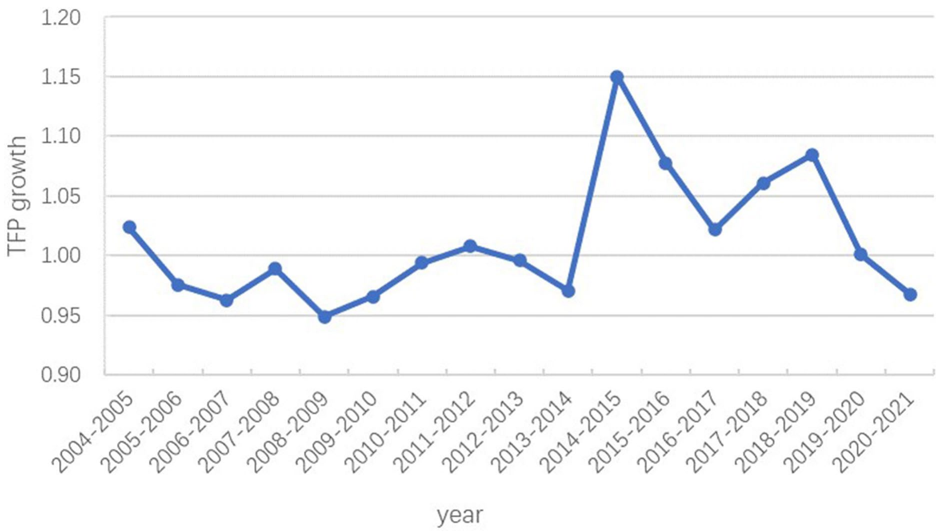

FIGURE 1
Changes in raw milk TFP, 2004–2021.

4 Empirical analysis

4.1 Measurement and decomposition of raw milk TFP growth

Raw milk TFP growth was measured and decomposed into two components by the Malmquist productivity index: technical efficiency and technological progress (Figure 1). Raw milk TFP growth has shown a significant growth trend with an average growth rate of 1.1% and the growth was mainly driven by technological progress (techch = 1.014). After grouping the sample provinces (small-scale, medium-scale, large-scale),[6] it was found that the efficiency growth of small-scale farming (TFP growth = 1.012) was higher than that of medium and large-scale (TFP growth = 1.002, 1.007). The efficiency decomposition found that the main source of motivation for TFP growth in all three production modes was technological progress, and that the technical efficiency of medium- and large-scale showed a downward trend. Since 2008, to ensure the quality and safety of milk sources and enhance the competitiveness of the dairy industry, the Chinese government has vigorously promoted the process of scaling up through financial support, tightening market access, and encouraging cooperative operations, greatly accelerating the process of small-scale ranches exiting the market. The main reason for the better performance of small-scale TFP growth may be that with the trend of scale-up of dairy farming, less efficient small-scale farms have withdrawn from the market in large numbers. While medium and large-scale farms are more stable and will not exit the market easily, making the TFP growth performance of small-scale farms better than medium and large scale.

4.2 Benchmark regression

Taking the measured TFP growth as the explained variable and the market concentration index HHI index as the core explanatory variable, the paper verifies the impact of downstream dairy market concentration on the growth of upstream raw milk TFP. The regression results are shown in Table 2.

In this paper, we first test the validity of the fixed effects model. Through the F-test it was found that the individual effect is significant and the fixed effect model is superior to the mixed regression. Through Hausman test it was found that individual effects were not in the form of random effects and the fixed effects model was superior to the random effects model. However, through further testing of LSDV method it was found that the area fixed effects were poor. Many area dummy variables were not significant and the area fixed effects may dilute the role of key explanatory variables. In view of this, the results of all three regressions are shown below for comparative reference.

Short panel data have little individual information and the autocorrelation problem of the disturbance term is difficult to deal with, so it is generally assumed to be independently and identically distributed. While for the long panel it is necessary to consider the possible heteroskedasticity and autocorrelation problems. In view of this, the Greene-Wald test was used in this paper to test for between-group heteroskedasticity. It was found that $p = 0.6929$ and there was no between-group heteroscedasticity. The Wooldridge–Wald test was used to test for between-group autocorrelation. It was found that $p = 0.002$, there was between group autocorrelation. Breusch-Pagan LM test was used to test for contemporaneous correlation between groups. It was found that $p = 0.000$, and there was contemporaneous correlation. Due to the existence of inter-group autocorrelation and contemporaneous correlation in the perturbation terms, the results of using the least squares (OLS) method may produce a large bias, so

6 In this paper, the number of scale Q classification standard: small scale(0 < Q≤50), medium scale (50 < Q≤500), large scale(Q>500). The classification standard is based on the National Compendium of Agricultural Products Cost and Benefit Information.

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TABLE 2 Benchmark regression results.

	Pooled regression		Random effects model		Fixed effects model	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Core explanatory variable						
HHI	−0.0715***	0.0151	−0.0671***	0.0203	−0.1711***	0.2300
Control variables						
SCALE	0.0028	0.0027	0.0012	0.0018	−0.0151	0.0153
WAGES	0.0837***	0.0337	0.0885***	0.0153	0.0874***	0.0183
PROFIT	−0.0007**	0.0003	−0.0007***	0.0002	−0.0023***	0.0004
PRICE	0.0144	0.0596	−0.0068	0.0287	0.1010	0.0441
RTC	−0.0039	0.0068	−0.0021	0.0042	−0.0213	0.0095
HAE	−0.0026	0.0089	0.0003	0.0039	0.0277***	0.0096
FAI	0.0032	0.0032	0.0020	0.0015	0.0025	0.0017
Regional fixed effects					Controlled	
Time fixed effect					Controlled	

***, **, and * indicate 1, 5, and 10% significance levels, respectively.

we use the Feasible Generalized Least Squares (FGLS) method for parameter estimation instead of OLS.

The regression results with the HHI index as the core explanatory variable show that the increase of downstream market concentration is unfavorable to upstream raw milk TFP growth. Downstream agricultural market concentration is detrimental to the development of high quality of upstream agricultural production, which is in line with the expectation of our H1 hypothesis. To test whether there is a nonlinear characteristic of this negative impact, the quadratic term of the key explanatory variables is added based on Equation 6. The regression results are shown in Table 3. The results reveal that the coefficient of the quadratic term is significantly negative, showing a nonlinear inverted "U" type relationship. This indicates that the downstream market concentration is too high or too low will have a negative impact on the upstream raw milk production. Only by maintaining a moderate downstream market concentration can we maximize the TFP growth of upstream raw milk. However, the value of HHI ranges from 0 to 10,000, which means that there is a monotonically decreasing trend in the sample interval, so there is no inverted "U"-shaped relationship. The panel threshold effect model was used to verify again and the threshold existence test was not passed. Therefore, the negative impact of downstream market monopoly on raw milk production efficiency of upstream farming is monotonous and linear.

The sample was divided into three groups of small-scale, medium-scale and large-scale, and the test of scale heterogeneity was conducted. The regression results are shown in Table 4. The results show that downstream market concentration positively affects the TFP growth of raw milk for small-scale farms and negatively affects the TFP growth of large-scale and medium-scale farms. Hypothesis H1 is verified.

Since the new century, China's dairy industry has been developing at a very fast pace in terms of scale. According to the report of the National Dairy Cattle Industry Technology System, the proportion of large-scale farming with more than 100 heads in China has reached 73% in 2022, which is more than 50% compared with 2008. The rapid increase in the proportion of large-scale farming also means many

TABLE 3 Regression results with quadratic terms of core explanatory variables.

Variables	Coefficient	Standard error
HHI	18.1146***	2.3678
HHI*HHI	−57.6012***	7.4440
Control variables	Controlled	
Regional fixed effects	Controlled	
Time fixed effect	Controlled	

***, **, and * indicate 1, 5 and 10% significance levels, respectively.

small-scale farmers have withdrawn from the market, and most of these small-scale farms have relatively poor production efficiency. On the one hand, downstream concentration further deteriorates the survival environment of small-scale farms and accelerates their exit from the market. On the other hand, oligopolistic dairy enterprises also prefer and support the development of large-scale farms to ensure stable supply, thus further accelerating the process of dairy farming scale-up. Under the dual mechanism, the downstream concentration trend indirectly promotes the TFP growth of small-scale dairy farming through market elimination. In addition to market elimination, oligopolistic dairy enterprises have higher requirements for raw milk production standards, thus promoting production equipment and process standardization, digitalization and intelligence, which drives TFP growth. However, the equipment and processes of medium- and large-scale farms are initially at a higher level, who are less affected by downstream concentration. This may also be an important reason why downstream concentration has a positive impact on small-scale TFP growth. It should be noted that although the concentrated downstream market drives the market exit of inefficient farms, there are still some farms that insist on production. These small farms that are in production still face negative impacts from downstream compression, hindering the improvement of production efficiency. Therefore, we can see that in Table 4, although the results of the model have a significant positive impact, the significance is not very strong, which is the result of a mixture of positive and negative effects.

TABLE 4 Subgroup regression results considering size heterogeneity.

variables	Small-scale		medium-scale		large-scale	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
HHI	0.3353*	0.1841	−0.0775***	0.0167	−0.0934***	0.0170
Control variables	Controlled		Controlled		Controlled	
Regional fixed effects	Controlled		Controlled		Controlled	
Time fixed effect	Controlled		Controlled		Controlled	

***, **, and * indicate 1, 5, and 10% significance levels, respectively.

4.3 Robustness testing

4.3.1 Replace core explanatory variable

Referring to related studies, the CR4 index, CR8 index, EI index, and Gini coefficient are used instead of the HHI index as the key explanatory variables to measure downstream concentration. The formula for each variable is as follows:

$$CR_n = \frac{\sum_{i=1}^{n} X_i}{\sum_{i=1}^{N} X_i} \quad (8)$$

where n represents the market concentration of the top n enterprises, with n typically taking the value of 4 or 8; X_i represents sales; N is the total number of companies in the industry. The higher the CR index is, the higher the market concentration is.

$$\text{EI} = \frac{1}{lnN} \sum_{i=1}^{N} S_i \cdot \ln\left(\frac{1}{S_i}\right) \quad (9)$$

where Si represents the market share; N represents the total number of companies in the industry. The larger the EI index, the lower the market concentration.

$$\text{Gini} = \frac{S}{P} \quad (10)$$

where S represents the area of inequality surrounded by the Lorenz curve and the absolute mean in the Lorenz curve diagram; P represents the area of inequality in the half area of the Lorenz curve diagram excluding S. The areas of S and P are calculated using the calculus method. The larger the Gini coefficient, the higher the market concentration.

The regression results are shown in Table 5. CR4, CR8, and Gini coefficients are negatively correlated with raw milk TFP growth. EI index is positively correlated with raw milk TFP growth. That is, after replacing the core explanatory variables, the previous conclusion still holds.

4.3.2 Replace empirical method

Considering that the raw milk TFP growth are all truncated data >0, the panel Tobit model is used for robustness. Table 6 gives the regression results for the random effects panel Tobit model and the two-way fixed effects panel Tobit model. The two-way fixed effects model uses the LSDV method. The results in Table 6 show that downstream market concentration still plays a negative role in raw milk TFP growth, consistent with the previous findings.

TABLE 5 Robustness test results of replacing core explanatory variables.

Variables	Coefficient and standard error			
CR4	−0.9722*** (0.1307)			
CR8		−0.9912*** (0.1332)		
EI			2.6482*** (0.3559)	
Gini				−2.4520 (0.2993)
Control variables	Controlled	Controlled	Controlled	Controlled
Regional fixed effects	Controlled	Controlled	Controlled	Controlled
Time fixed effect	Controlled	Controlled	Controlled	Controlled

***, **, and * indicate 1, 5, and 10% significance levels, respectively. Standard error in parentheses.

4.3.3 Replace the measurement method for TFP growth

The Malmquist productivity index is not as good as the stochastic frontier production function model in dealing with stochastic shocks. The stochastic frontier production function model is used here to measure the TFP growth of raw milk, and one-step regression is used to empirically test the relationship between downstream concentration and upstream TFP growth. The production function is set as a transcendental logarithmic production function with time effects. The results of the one-step regression are shown in Table 7. The results show that downstream market concentration still plays a significant negative role in upstream raw milk TFP growth, further verifying hypothesis H1. It is worth noting that the use of the generalized likelihood ratio test found that the model did not pass the applicability test, indicating that the applicability of the stochastic frontier production function model is poor, which is also the reason why the benchmark regression in this paper uses data envelopment analysis. The productivity gap between provinces is small, in which case the stochastic frontier production function is not suitable because it has to take into account the random shocks. The conclusions herein serve only as a comparative reference to the original method.

TABLE 6 Robustness test results for the replacement of empirical methods.

Variables	Random effects-Tobit model		Two-way fixed effects-Tobit model	
	Coefficient	Standard error	Coefficient	Standard error
HHI	−0.0715***	0.0235	−0.1919***	0.0335
Control variables	Controlled		Controlled	
Regional fixed effects	Controlled		Controlled	
Time fixed effect	Controlled		Controlled	

***, **, and * indicate 1, 5, and 10% significance levels, respectively.

TABLE 7 Robustness test results for replacing TFP growth measures.

Variables	Coefficient	Standard error
HHI	−0.1398***	0.0253
Control variables	Controlled	
Regional fixed effects	Controlled	
Time fixed effect	Controlled	

***, **, and * indicate 1, 5, and 10% significance levels, respectively.

4.4 Mechanism analysis

This paper first follows the conjecture of theoretical hypothesis H2a to verify the possible positive mechanism. Technical efficiency is obtained through the decomposition of Malmquist productivity index, which measures the allocation of resource inputs to raw milk production, reflecting the management level. The expansion market brought about by the oligopoly trend in the dairy market is partly occupied by foreign raw milk, so milk production is used here as a measure of domestic raw milk market demand. The regression results are shown in Table 8.

The results show that downstream market concentration has a significant positive impact on upstream technical efficiency and milk production. The increase of dairy market concentration promotes the improvement of technical efficiency in dairy processing and then promotes the improvement of technical efficiency of raw milk through the spillover effect.

In addition, the downstream centralization trend has given rise to several large-scale dairy enterprises. This concentration of resources makes China's dairy industry more advantageous in the face of international competition. Large dairy enterprises are also more willing to invest in the development of the overall market, not just their own market, such as promoting healthy diets and the high value of milk, etc. Expansion of the dairy market creates a good space for the development of domestic dairy farming, thus promoting the development of TFP.

In summary, the downstream market concentration of dairy products promotes the upstream raw milk TFP growth through the improvement of technical efficiency and market demand expansion to a certain extent. Hypothesis H2a is proved.

In accordance with theoretical hypothesis H2b, net profit and technological progress index are used as explanatory variables, respectively, to test the negative mechanism of downstream market concentration on upstream raw milk TFP growth. The technological progress index is obtained by decomposing the Malmquist productivity index. The regression results are shown in Table 9.

The results with the level of raw milk production profit as the explanatory variable show that the increase of dairy market concentration will have a significant negative impact on the level of raw milk production profit, which is consistent with our expectation. Concentration in the dairy market will strengthen the market trading position of dairy enterprises. Dairy enterprises in a dominant position can capture excess profits and transfer business risks by suppressing prices and controlling the volume of purchases, thus hindering the growth of raw milk TFP.

The estimation results with technological progress index as the explanatory variables show that the concentration in dairy market not only does not bring opportunities for technological innovation in raw milk production, but also suppresses its technological progress. There may be three main reasons. First, the differences in the technological systems upstream and downstream of the supply chain leads to little role for technological spillovers. In fact, the technological progress in dairy farming may be more closely related to its upstream equipment providers. Second, there are inherent impeding forces to technology spillovers. In oligopolistic markets, such impeding forces are even stronger and the effect of spillovers is diminished. Thirdly, constrained by the downstream price suppression, the profit level of dairy farming is low. Dairy farms cannot afford to invest in advanced technology. In addition, during the economic downturn, dairy enterprises control prices and volumes to transfer business risks, making the survival environment of dairy farming more unstable. Farmers have insufficient expectations of the benefits of advanced technology, which leads to a lack of technological progress and affecting TFP growth.

In summary, the downstream market concentration of dairy products suppresses the TFP growth of raw milk through the mechanism of squeezing production profit and hindering technological progress. Hypothesis H2b is confirmed.

It is worth noting that the coefficients of the explanatory variables with technological progress are much larger than the coefficients of the explanatory variables with technological progress as the explanatory variables, which indicates that the effect of the mechanism of hindering technological progress is much stronger than that of the mechanism of improving technological efficiency.

Through the above analysis, it can be found that the downstream market concentration of the dairy industry has both positive and negative impacts on the TFP growth of upstream raw milk. However, the negative impact plays a major role, resulting in an overall negative impact. Hypothesis H2 is proved.

4.5 Further discussion

The above empirical results show that increased market concentration in the downstream slows downstream raw milk TFP growth by squeezing production profits and hindering technological progress. Based on this, this part explores which factors can mitigate

TABLE 8 Test results of positive mechanism.

	Technical efficiency		Milk production	
	Coefficient	Standard error	Coefficient	Standard error
Core explanatory variable				
HHI	0.0293**	0.0114	0.4216***	0.0435
Control variables				
TFPC			0.0637	0.0682
SCALE	0.0054	0.0094	0.2377***	0.0393
WAGES	0.0247	0.0245	−0.0392	0.0428
PROFIT	−0.0006**	0.0002	0.0013	0.0008
PRICE	0.0269	0.0430	0.0652	0.0931
RTC	−0.0067*	0.0040	0.0215	0.0168
HAE	0.0017	0.0082	−0.0675***	0.0258
FAI	0.0002	0.0014	0.0084*	0.0047
Regional fixed effects	Controlled		Controlled	
Time fixed effect	Controlled		Controlled	

***, **, and * indicate 1, 5, and 10% significance levels, respectively.

TABLE 9 Test results of negative mechanism.

	Net profit		Technical progress	
	Coefficient	Standard error		Coefficient
Core explanatory variable				
HHI	−4.9583**	2.3449	−0.1947***	0.0145
Control variables				
TFPC	−31.8515**	3.7285		
SCALE	−8.1883***	1.2456	−0.0064	0.0100
WAGES	−22.0800***	2.8808	0.0407**	0.0196
PROFIT	–	–	−0.0005	0.0003
PRICE	81.4016***	4.5341	0.0817**	0.0378
RTC	3.4600***	1.1233	−0.0208***	0.0074
HAE	7.4966***	1.2052	−0.0010	0.0105
FAI	0.2571	0.3362	−0.0003	0.0021
Regional fixed effects	Controlled		Controlled	
Time fixed effect	Controlled		Controlled	

***, **, and * indicate 1, 5, and 10% significance levels, respectively.

the above negative impacts by introducing interaction terms of key explanatory variables and other variables. The regression results are shown in Table 10.

The regression results show that higher wage levels, raw milk prices and refined-to-rough ratios are all conducive to attenuating the negative impact of downstream monopolization on upstream production. The increase of wage level is conducive to recruiting better employees and enhancing employee motivation, which can better cope with the price and supply suppression of downstream monopoly, thus weakening the negative impact of the increase in downstream concentration. The increase of raw milk price can effectively improve the profit margin of dairy farming. Furthermore, it usually reflects the market environment of insufficient supply. The negotiating position of farmers will rise. This will have a good mitigating effect on the negative mechanisms that squeeze production margins and impede technological progress. The production and quality of raw milk largely depend on feed. Reasonable feed structure can not only reduce the input of cow feed costs, but also maximize the milk production performance of cows. There is still room for optimization of the current feed structure. Appropriately increasing the ratio of concentrate to roughage will help alleviate the negative impact of downstream market concentration.

High net profit retention and fixed asset ratios will further exacerbate the negative effects of downstream monopolization. High

TABLE 10 Test results of the moderating effect of other variables on raw milk TFP growth.

Variables	Coefficient and standard error						
	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5	Regression 6	Regression 7
HHI	−0.1715*** (0.0251)	−0.2106*** (0.0353)	−0.1018*** (0.0287)	−0.3205* (0.0723)	−0.4384*** (0.0636)	−0.2028*** (0.0450)	0.4238 (0.2655)
HHI*SCALE	0.0005 (0.0048)						
HHI*WAGES		0.0481* (0.0247)					
HHI*PROFIT			−0.0782*** (0.0192)				
HHI*PRICE				0.1580** (0.0615)			
HHI*RTC					0.2990*** (0.0652)		
HHI*HAE						0.0454 (0.0460)	
HHI*FAI							−0.5893** (0.2662)
Control variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Regional fixed effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Time fixed effect	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled

***, **, and * indicate 1, 5, and 10% significance levels, respectively. Standard error in parentheses.

profit retention represents a lack of investment in other areas such as technology and human resources. This negative operational strategy makes it more difficult for dairy farmers to cope with downstream oligopolies. Farms with a high proportion of fixed assets are generally medium-scale farms. Small-scale farms invest less in fixed assets. Large-scale farms have strong scale effect and high utilization rate of fixed assets. Medium-scale farms have a high share of fixed assets but a poor scale effect and utilization performance, thus forming a drag on them. Therefore, it is also necessary to optimize the proportion of fixed assets appropriately.

5 Conclusions and recommendations

The paper empirically examines the impact of rising downstream market concentration on upstream raw milk TFP growth using a two-way fixed-effects model with data of dairy farming in 10 provinces across China from 2004 to 2021. The results show that downstream market concentration is detrimental to upstream raw milk TFP growth. However, there is scale heterogeneity in this negative impact, in which there is a positive impact on raw milk TFP growth of small-scale farming and negative impact on medium- and large-scale farming. This negative impact is the result of both positive and negative mechanisms. Although downstream market concentration drives upstream raw milk TFP growth to a certain extent through technical efficiency improvement and market demand expansion, it mainly suppresses raw milk TFP growth through the mechanism of squeezing production profit and hindering technological progress. Further analysis shows that wage increases, raw milk price increases and improvements of refined-to-rough ratios all help to mitigate the negative effects of downstream monopolization to a certain extent, but net profit retention and high fixed asset ratios further exacerbate the negative effects.

To mitigate the challenges of rising downstream market concentration on upstream production, enhance raw milk TFP growth and promote high-quality agricultural development, the paper proposes the following suggested measures.

First, improve the market position of farmers. Weakness of upstream farming in the market is the root cause of downstream monopolization hindering raw milk TFP growth. The market position of farmers can be improved from two aspects: dairy farmer organization and cost reduction. On the one hand, the degree of organization of dairy farmers should be strengthened. We should encourage and support the development of dairy farmers' cooperative organizations and breeding associations. On this basis, build a price consultation and negotiation mechanism with dairy enterprises. Through scientific system design, dairy farmers are shaped into monopoly subject form. It will drive the shift from asymmetric to symmetric competition between upstream and downstream of raw milk market and from a buyer's market to an equilibrium market. On the other hand, it should continue to reduce the cost of dairy farming. Through the improvement of dairy cattle breeds, scientific feeding, scientific epidemic prevention and management, on the basis of guaranteeing the quality of raw milk, reduce production costs. The state should set appropriate protection or subsidy policies for domestic dairy farming and reduce the cost gap with foreign raw milk to create development buffer space for China's raw milk.

Second, strengthen the regulation of downstream monopolistic behavior. Developed countries in the dairy industry have generally formulated strict laws to regulate oligopolistic dairy enterprises and protect dairy farmers. For example, New Zealand introduced the Dairy Restructuring Act. United States introduced the Dairy Gross Profit Coverage Program, the Dairy Donation Program and the Dairy Payout Program. China should also strengthen the regulation of dairy market monopoly and protection of dairy farmers, but it is worth noting that there is nothing inherently wrong with an oligopolistic market structure. Monopoly has a series of positive effects such as expansion of market demand, promotion of technical efficiency and development of technological progress. What needs to be guarded against is the unlawful behavior of taking advantage of the monopoly position to seize excessive profits. Therefore, China should fully utilize the power of laws and regulations. On the basis of the Anti-Monopoly Law, etc., it should further clarify the situation of abuse of market dominance by dairy enterprises. It should also increase the investigation and punishment of the industry's anti-monopoly and abuse of dominant market position, outlaw the existence of overbearing contracts between dairy enterprises and dairy farmers. Thus, the positive effects of the oligopolistic market structure can be fully utilized and its negative effects curbed.

Third, build a closer upstream and downstream benefit linkage mechanism. Constructing upstream and downstream benefit linkage mechanism is an effective means to avoid downstream oligarchs squeezing upstream dairy farmers' production profits and transferring business risks. At the same time, it can also incentivize the oligarchic dairy enterprises to take the initiative to promote the spillover of advanced management and technological innovation to the upstream, effectively promoting the growth of raw milk TFP. Therefore, China should carry out the "top-level design" from the system and build a closer upstream and downstream cooperation mechanism and benefit-sharing pattern. Dairy enterprises and dairy farmers should be guided to establish contractual, profit-sharing and equity-type cooperation pattern to improve the ability of dairy farmers to participate in the distribution of profits in the industrial and commercial sectors. A community of interests with "shared resources and risks" need to be built through the participation of dairy enterprises in farms, holding farms, self-built farms, and other specific forms of cooperation and promote the synergistic development of all stakeholders in the industry chain

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ZY: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. GF: Resources, Supervision, Writing – review & editing. HL: Conceptualization, Data curation, Investigation, Methodology, Project administration, Writing – review & editing. HP: Formal analysis, Investigation, Project administration, Resources, Writing – review & editing. XD: Conceptualization, Formal analysis, Funding acquisition, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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