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Enhancing productivity on suburban dairy farms in China

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Abstract

Dairy farms in China's suburban areas have been playing an important role in providing urban markets with fresh milk. With the rising demand for fluid milk and dairy products in the cities, there is a perception that small and scattered dairy farms in China's provinces are gradually disappearing and more concentrated dairy cattle farming is being formed near suburban areas. This article uses farm-level survey data and stochastic input distance functions to make estimates of total factor productivity (TFP) on suburban dairy farms, as well as for the entire dairy sector. The results show that over the past decade TFP growth has been positive on suburban dairy farms, and this rise in productivity has been driven mostly by technological change. However, at the same time we find that, on average, the same farms have been falling behind the advancing technical frontier. We also find one of the drivers of the suburban dairy sector is the relatively robust rate of technological change of these farms, which has been more rapid than on farms in the dairy sector as a whole. The results suggest that efforts to achieve greater adoption of new technologies and better advice on how to use the technologies and manage production and marketing within the suburban dairy sector will further advance productivity growth in the sector.

JEL classification: D240, Q100, Q160

Keywords: Distance function; Productivity growth; Technical inefficiency; China; Suburban dairy farms

1. Introduction

Milk production in China is struggling to keep up with demand. While output has increased from 5.8 million metric tons in 1995 to 17.5 million metric tons in 2003 (NSBC, 1996, 2004), demand, especially in urban areas, has increased even more dramatically. As a result, China's net imports of dairy products have exploded from US$28 million in 1995 to US$295 million in 2003.

Farm productivity is a key variable needed to answer questions about China's future dairy self-sufficiency and net trade situation. The rapid growth in China's output has thus far been driven primarily by increased animal numbers rather than by higher yields (Fuller et al., 2005; Yang et al., 2004). So, what have been the trends in dairy farm productivity in China? Although yields have not risen by much, has total factor productivity (TFP) increased? If it has, has productivity growth been due to technological change or to more efficient use of existing milk production technologies? In this article we seek answers to these questions.

However, unlike our previous work in Rae et al. (2006), in this article, we center our attention on dairy production in China's suburban production districts. While there are no national data on which a definitive set of statistics can be based, it is commonly believed that the location of milk production in China is moving to suburban areas, closer to the major markets and the urban-based milk processing centers (Zhou et al., 2002). Under a set of plausible assumptions, we estimate that between 40% and 50% of China's dairy production is occurring in the city districts and/or the surrounding suburban counties of China's major cities.[1] As a consequence, it is important to understand the nature of production in these suburban districts. Since suburban dairy farms tend to be somewhat larger, more intensive,

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[1] From provincial statistical yearbooks we were able to calculate the share of total milk production from a subset of our sample cities. Extrapolating these calculations to the national level produced the above estimate.

and more market-oriented than the national average, could it be possible that productivity growth is more rapid on such farms? This is important to know as China's policymakers on both the agricultural production and environment quality sides of government develop plans to meet their goals.

In the next section we describe China's dairy farm systems, including the suburban milk production sector, followed by a discussion of the data and some descriptive statistics about suburban dairy farms. We then use a stochastic distance function methodology to estimate productivity growth in the suburban milk production sector, followed by a discussion of our results. We also compare the results from the suburban sector with the dairy sector as a whole. The article concludes with some policy implications of our findings and speculates what China's dairy production structure and geographical location will be in the coming years. Unfortunately, because of the absence of information on the adverse environmental impacts of dairy production, we are unable to quantitatively examine this issue in our article.

2. Dairy farm systems in China

Dairy systems in China can be classified into three general types. Pastoral dairy farm systems are found mainly in the relatively remote rural areas of Inner Mongolia, Tibet, Xinjiang, Qinghai, and Gansu, where cows depend primarily on pasture grazing (Gao, 2004). Although traditionally these systems produce a large share of China's milk, much of it is consumed on the farm. Cropping area production systems are located mainly in the rural areas of Heilongjiang, Liaoning, Hebei, Jiangsu, Shandong, Henan, Sichuan, Yunnan, Shaanxi, and Ningxia provinces, where cows are kept mostly in backyard sheds and are fed more grains and crop residues than those raised in pastoral systems (Zhou et al., 2002). More commercial than pastoral systems, in the 1980s and early 1990s, cropping area production systems contributed a larger share of China's milk. Suburban dairy farm systems, which are mainly found in the rural areas around Beijing, Tianjin, and Shanghai as well as the suburban areas of all provincial capital cities and other large-sized cities around China (currently there are three such cities—Qingdao, Xiamen, and Ningbo), differ from the other systems by their location in suburban areas, their relatively large scale, and their higher reliance on market-purchased feed. In this study, we focus primarily on suburban dairy farms.

While the term "suburban" is difficult to define and differs from country to country, we use the word here in a context that is China specific. In our study—because the data are so organized—the term suburb refers to the rural areas in city districts and counties that surround China's large cities and are under the administrative jurisdiction of the city government. Our data come from the suburban areas of 35 cities, including Beijing and Tianjin, and 31 of the 35 sample cities are provincial capitals. Each city on average had 12 city districts and counties under its jurisdiction, contained over 4 million people (not including temporary migrants), and covered more than 10,000 square kilometers.

Unfortunately, since there are no statistical data that report total cow numbers or dairy output systematically for the entire country, we have to rely on indirect methods (using information from various studies and reports) to gauge the size of the suburban sector. According to MOA (2003), suburban dairy farms produced 54.4% of total milk output that supplied the demand of Beijing, Tianjin, and Shanghai in 2000. Likewise, suburban dairy farms in a large Sichuan provincial city, Zigong, produced more than 50% of the total milk consumed in Zigong city in 2003 (ZAB, 2003). Even in Heilongjiang province (which produced 17.2% of all of China's dairy output in 2003), dairy farms are concentrated in the suburban areas of the large cities and nearly 80% of the province's dairy cattle are raised in the suburban districts of Harbin, Daqing, and Qiqihar.

3. Factors that encourage the cows to come to town

Several factors have encouraged the development of suburban dairy farms in China. First, demand for dairy products is primarily concentrated in suburban areas where consumers have a strong preference for fresh milk over other substitutes such as soybean milk. This demand has encouraged the development of milk production in suburban areas of large cities and their geographical proximity has in several cases helped overcome the lack of specialized cooling transportation facilities (Zhou et al., 2002). Second, the government has implemented a wide range of measures to promote the development of suburban dairy farms, including the provision of concessional loans for investment, feed subsidies, the supply of improved breeds, and the provision of technical assistance to producers (Wu et al., 2006). Local governments have provided assistance in establishing large livestock farms to secure supply to nearby urban consumers. These may include investment subsidies (direct grants or subsidized credit) to farmers to move their livestock to special designated sites with the objective of reducing environmental problems in the villages. From a survey of 50 randomly selected villages in Greater Beijing, Wu et al. (2006) find that 26% of new dairy farms had received government support, including subsidized credit, provision of additional land, and subsidies on cow purchases. Other assistance includes that delivered through the Food Basket Project and the School Milk Program to encourage healthy diets and food diversity. Third, the injection of foreign capital and the introduction of advanced technologies have helped promote suburban milk production (RTDDI, 1997; Tuo, 1999). Since the mid-1980s, international organizations and foreign governments have provided technical assistance in developing China's suburban dairy farms. For example, the United Nations Development Programme (UNDP) sponsored a project to develop dairy production in six major cities during 1984–1990.[2] The EU implemented an even larger project in 20 cities

[2] The six cities are Nanjing, Xian, Shanghai, Being, Wuhan, and Tianjin.

during 1990–1994.[3] With a total funding of US$156 million, these projects have made a significant contribution to the increase in suburban milk production. Large suburban dairy demonstration farms have been successfully constructed in several large northern cities (MSTC, 2004).

Data collected by the Center for Chinese Agricultural Policy from the agricultural bureaus in Beijing and Hebei show that in recent years there has been a rapid expansion of processing facilities in one of China's many suburban areas (in this case, that of Beijing). Before 1990, when dairy demand still had not started growing, national dairy processing firms established their processing plants in only three of the counties in and around Beijing (Fig. 1, Panel A). During the 1990s, the pace of plant expansion accelerated (Panel B). During this period, plants opened in six or more counties. The density of plant construction also rose. Most of the plants were next to or adjacent to the center of Beijing. When comparing Panels A and B, it is easy to see how the pace of plant openings not only rose between the 1980s and 1990s; plants are perceptibly being located in the immediate suburban districts and counties of the main population centers of Beijing.

4. Rising production and shifting technologies

Since the 1990s, the growth in the number of dairy cows in suburban areas appears to have matched or exceeded the rate of growth in the national dairy herd. For example, in Beijing, our data show the total value of output of dairies almost doubled between 2000 and 2004. About one-third of the new volume came from new dairy farmers; two-thirds of the increase came from farmers who expanded their dairy herds. Suburban dairies are growing rapidly in total numbers through the addition of new dairies and from the expansion of herd size of the existing farmers.

The rapid growth of dairy output is matched by changes in the ways that dairies are producing and marketing their product. Driven by demand-side pressures, intense competition has emerged among processing companies for raw milk (Liao, 2003). One realization of this competition is that it has encouraged the recent phenomenon of dairy cattle "concentration centers" in suburban areas (Miao and Jiang, 2003; MOA, 2003; Yi, 2005). Small and scattered dairy farmers in the countryside are driving their cows into the concentration centers where they can rent space for their cows, and/or buy cows to start their business, and enjoy relatively modern production and marketing services such as access to concentrate feed, new owner training programs, animal disease control, milking facilities, milk collection, and transportation (Zhang, 2005).

[3] The 20 cities are Shenyang, Dalian, Qingdao, Hefei, Hangzhou, Changsha, Guangzhou, Chengdu, Chongqing, Fujian, Nanchang, Wuxi, Suzhou, and Guilin in addition to the previous six cities.

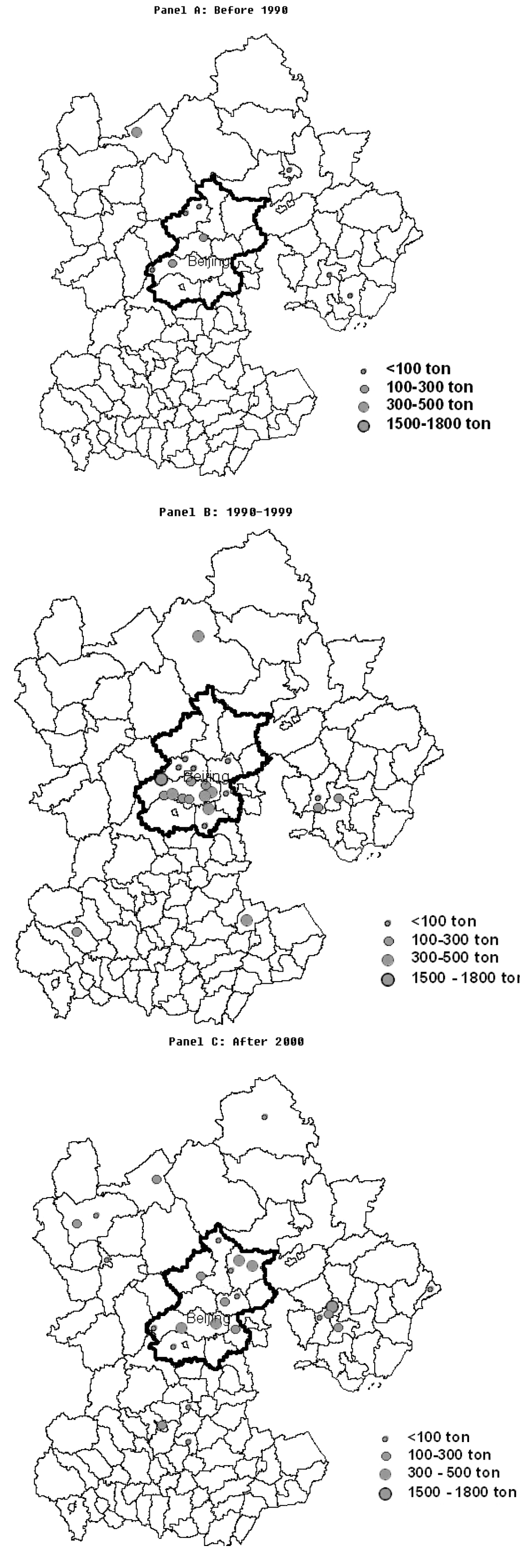

Fig. 1. New dairy processing capacity in greater Beijing, 1980s to 2000.

Concentration centers are but one type of several new institutional arrangements that have appeared in the suburban dairy sector. According to Wu et al. (2006), when assessing the main ways in which dairy cows are milked and the output is marketed in 30 sample communities in the suburbs of Beijing, there are more than 10 distinct ways that farmers produce and sell their milk. Moreover, the shift among milking and marketing institutions is occurring rapidly; at least 30% of farmers shifted their approach to milking or marketing between 2000 and 2004. Clearly, while this situation shows that dairy production is extremely dynamic in China today, such wholesale shifts in institutions (aside from the rise in the number of dairies) may mean that there is considerable inefficiency as dairies seek to learn how to produce and market in their new environment.

At the same time that *institutions* have been changing, so has the technology available to dairy farmers.[4] Dairy farmers—at times aided by processing firms or by the government—have sought means of changing their milking technology. Wu et al. (2006) find that the share of farmers in suburban dairies that use traditional genetics has fallen by half. Imports of improved genetics and the emergence of private and public efforts to improve the dairy stock have risen dramatically (Fuller et al., 2005). Data from suburban areas of Beijing also show that milking by machine has risen from 11% of total output in 2000 to 17% (of a much larger volume) in 2004 (Wu et al., 2006). Efforts by the government to promote animal health show up in the rising share of dairy cows that are vaccinated against endemic diseases and pests. Clearly, there is a rapid change going on in the institutions that are facilitating the production and marketing of dairy products as well as a large inflow of new technology. To the extent that such services are more accessible to dairies in suburban areas, it might be conjectured that this is part of the impetus for the rapid growth of suburban dairy production.

Such substantial investments in the development of new suburban dairy farms since the early 1990s, along with planned future investments, have contributed and can be expected to continue to contribute to the dramatic expansion of China's milk production capacity (although as is discussed below there may be other pressures to shift production back outside of suburban areas in the future). Where is this growth coming from? Is it only from the total number of cows or is it from increasing productivity? If productivity has changed, is the rise (or fall) in productivity due to increases (decreases) in technical efficiency or technological change? In short, to understand the future of suburban farming, and whether or not growth in the sector will add to increased production primarily through increases in cow numbers or by enhancing productivity, remains to be evaluated.

[4] Unfortunately, we do not have the data that would allow us to distinguish between the effect of technological change and the effect of institutional change on productivity. Certainly both have the potential to affect productivity. In this section we describe the changes to illustrate that both of these phenomena are affecting the dairy industry.

5. Cost of production and China's suburban dairy farms

The main source of information for examining the productivity of suburban dairy farmers is the National Agricultural Commodity Production Cost and Return Data (ACPCRD). Published by the State Development Planning Commission (SDPC), the ACPCRD provides detailed output and cost information for many farming enterprises in China, including milk production. It also provides the cost data for suburban (according to our definition) livestock farms that are used in this study. While the SDPC's data for crops have been widely used (e.g., Huang and Rozelle, 1996; Jin et al., 2002; Tian and Wan, 2000), this does not appear to be the case for the national livestock data (we are only aware of Rae et al., 2006, and Ma and Rae, 2004). To the best of our knowledge the cost data for suburban livestock production have never been analyzed.

The SDPC survey of suburban fresh milk production covers 35 large and medium provincial, municipal, and autonomous regional capital cities (except for Tibet) over 12 years (1992–2003). The survey also collects farm data for the dairy industry as a whole (suburban and rural farms) but separate results for nonsuburban farms are not published. Prior to publication the cost data are summarized in terms of cohorts, by averaging similar farms in like areas for each observation. We excluded any city or region that had fewer than three observations over the 1992–2003 period. This resulted in unbalanced data panels of 137 observations for specialized household suburban dairy farms and 230 observations for state and collective suburban dairy farms, and 120 and 194 observations, respectively, for specialized households and state-collective farms for the entire dairy sector.[5]

The cost of production database includes sufficient information to allow us to have detailed estimates of dairy inputs and outputs on a per cow basis. The data include milk yield per cow (kg), by-product value[6] per cow (yuan), farm size (cow numbers), labor inputs per cow (days), concentrate feed and

[5] The data used for our analysis, then, are based on farm-level data, but are aggregated by city and province. Specifically, each year statistical teams in each city and province randomly select a sample of household-level farms (or state-owned farms) and conduct a survey. After collecting the data, the city/provincial statistical teams enter the data and produce a set of cost and return data for each type of farm (household, state-owned, etc.). This process is repeated each year. Therefore, the data that are used in the analysis are essentially city/province-level data that are produced from specialized household-level surveys. This means that if a city/province had data for every year of our study period (1992–2003), the city/province would contribute 12 observations to the data set. This is essentially that same type of data that are available from the United States Department of Agriculture's (USDA) state-level panel, which is based on U.S. National Agricultural Statistical System's data collection effort. The SDPC did not publish the data of entire dairy sector for some years and some provinces so that the number of observations for the entire dairy sector is smaller than for suburban dairy farms.

[6] According to way in which the statistical team in the SDPC defined their terms in the ACPCRD, "by-products" of dairy farms include the value of calves (male and female), the value of animals that were retired and sold for slaughter, and manure.

fodder[7] consumption per cow (kg), and capital inputs per cow. We multiplied outputs and inputs per cow by animal numbers to construct total outputs (milk output, and by-product value deflated by the consumer price index) and total inputs. The survey also provides a breakdown of concentrate feed data into its grain and "other fine feed' (brans and meals) components. For the capital input we used the sum of depreciation, machinery maintenance, and small tool purchases, deflated by the agricultural machinery price index.[8]

Table 1 presents the average farm size, yields, and major input levels per cow for two types of suburban dairy farms (state-collective and specialized household farms) and for the whole dairy farm sample (i.e., suburban plus all other dairy farms). On average, the suburban state-collective farms have much larger herd sizes than the suburban specialized household farms. In 2001–2003, these were 548 and 27 cows, respectively. While the latter farm type increased average herd size by around 40% since 1992–1994, average herd sizes for the suburban state-collective farms increased by 90% over the same period. For both state-collective and specialized household farms, those located in suburban areas had somewhat larger average herd sizes than for the whole dairy sector. Averaged over 2001–2003, milk yields per cow were somewhat higher on suburban dairy farms than they were for the entire sample of dairy farms, and therefore would have been even higher on suburban farms relative to nonsuburban farms. This is true for both specialized household and state-collective farms. The same was true in 1992–1994 for suburban state-collective farms. The annual growth rate in yields between these two periods was faster for the suburban specialized household farms than for the entire sample of such dairy farms (1.84% vs. 1.49%), but was slower in the case of state-collective dairy farms (1.63% vs. 2.95%). Comparing both types of suburban dairy farms, average yields per cow on the state-collective farms were 17% higher than on specialized household farms in 2001–2003, and 19% higher in 1992–1994.

Average labor inputs per cow were lower on the suburban dairy farms than for the entire dairy farm sample in 1992–1994, irrespective of the type of farm. For both farm types, average labor input levels were similar in the suburban and entire farm samples, however, in 2001–2003. Between these time periods, labor usage per cow declined substantially. The average labor input per cow was also similar for both suburban specialized household and state-collective farms in both time periods. Capital inputs per cow were lower for both kinds of suburban dairy farm, in comparison with average capital inputs for the entire sample of farms, in 1992–1994. By 2001–2003, however, capital usage on the suburban dairy farms exceeded that for the whole industry. By this time, the suburban state-collective farms were more capital intensive than were the suburban specialized household farms, by a factor of about three, indicative of a much faster rate of capital accumulation per cow on the suburban state-collective farms.

Average feed inputs per cow on the suburban state-collective farms were higher than for the whole industry in 1992–1994, but were rather similar (but still higher for grains and fodder) by 2001–2003. In contrast, feed usage per cow on the suburban specialized household farms averaged less than for the whole industry in 1992–1994, but was similar to average input levels across the entire sector by 2001–2003. Within the suburban dairy farm sample, average feed use per cow was higher on the state-collective than on the special household farms in both 1992–1994 and 2001–2003. Over this time period, for both types of suburban dairy farms, average input levels per cow of each of the three feed types increased, with the largest increase being an almost threefold increase in the use of fodder on both farm types. If we use the sum of grain and other fine feed relative to milk yield per cow as a measure of feed efficiency, there is some evidence that efficiency has been higher on suburban than on nonsuburban farms. Over 2001–2003, for example, this ratio was 0.52 and 0.57 for suburban state-collective and special household farms respectively, compared with values of 0.53 and 0.59 for the whole dairy farm sample.

Farm size, production practices, yields, and input levels on suburban farms also vary substantially across locations within China (Table 2). This may mean that geographical location (which can determine climate and local cropping patterns, for example) could affect the productivity of suburban dairy farms in China. In 2003 herd sizes on the suburban state-collective farms averaged from 147 in Shijiazhuang to 3,500 in Wuhan. The range for suburban specialized household farms is much narrower, from just three cows in Qingdao to 152 in Tianjin. There appears no clear correlation among yields per cow and input levels. On the suburban state-collective farms in 2003, for example, Beijing (north) and Wulumuqi (far west) have the highest average yields (8,421 and 7,939 kg, respectively), while Zhengzhou (central) and Guangzhou (south) have the lowest (3,878 and 4,000 kg, respectively). Both of the high-yield locations have a higher use of other fine feed inputs per cow than do the lowest yielding areas, but this is not always the case for the grains, fodder, labor and capital inputs. The concentrate feed-to-yield ratio, as measured above, however, is lower for both high-yield locations than for the two low-yield areas. A similar story can be told for the suburban specialized household farms. The highest yields are found in the north (Tianjin and Beijing) and the lowest in the southwest (Kunming) and south (Nanning). Both the high-yield locations have

[7] Further explanation is required on the construction of the fodder input data. The published data include the value of the fodder input since 1992 but quantity data only for 1998 and later. Since we do not have access to a fodder price series with which to deflate the value data prior to 1998, we used the 1998–2003 data to regress fodder unit values on a range of variables that might reasonably be related to fodder prices (these were the labor wage rate on dairy farms, prices of concentrate feed, maize, wheat bran, rice bran and soybean, and a feed price index). From that equation we back-casted fodder prices to 1992.

[8] We do not incorporate a land variable into our analysis. First, land is not reported in our data. Second, although dairy farm sizes in pastoral areas are directly related to the amount of grassland that is available, most dairy cows on suburban dairy farms are raised in pens. Therefore, dairy farming in China is more like a plant or factory and might have relatively little to do with land. Perhaps more importantly, the size of land per cow most likely does not change over time, so this is almost certainly not driving changes in productivity.

Table 1
Comparisons of farm size, yields, and major input levels per cow: suburban and all dairy farms

Periods/types	Farm size	Yield (kg)	Labor (day)	Grains (kg)	Other fine feed (kg)	Fodder (kg)	Capital (yuan)
State-collective dairy farms							
1992–1994							
Suburban (1)	288	5,408	99	2,213	891	4,697	323
All farms (2)	208	4,652	107	1,981	726	3,422	351
(1)/(2) – 1	0.38	0.16	−0.07	0.12	0.23	0.37	−0.08
2001–2003							
Suburban (3)	548	6,255	64	2,222	1040	13,790	1,103
All farms (4)	512	6,041	64	2,143	1041	12,778	1,071
(3)/(4) – 1	0.07	0.04	−0.00	0.04	0.00	0.08	0.03
1992–2003							
Suburban (5)	396	5,798	77	2,262	945	11,465	709
All farms (6)	340	5,373	80	2,117	809	10,189	729
(5)/(6) – 1	0.16	0.08	−0.03	0.07	0.17	0.13	−0.03
Specialized household dairy farms							
1992–1994							
Suburban (7)	19	4,553	95	1,619	733	2,834	143
All farms (8)	15	4,576	113	1,880	829	3,001	160
(7)/(8) – 1	0.26	−0.01	−0.16	−0.14	−0.12	−0.06	−0.11
2001–2003							
Suburban (9)	27	5,366	66	2,171	863	7,392	374
All farms (10)	24	5,229	67	2,134	946	7,436	326
(9)/(10) – 1	0.13	0.03	−0.02	0.02	−0.09	−0.01	0.15
1992–2003							
Suburban (11)	23	4,898	83	1,961	732	5,279	236
All farms (12)	22	4,854	86	1,958	833	6,227	259
(11)/(12) – 1	0.03	0.01	−0.04	0.00	−0.12	−0.15	−0.09
Suburban dairy farms							
1992–1994							
Stat/coll.(13)	288	5,408	99	2,213	891	4,697	323
SHHD (14)	19	4,553	95	1,619	733	2,834	143
(13)/(14) – 1	14.2	0.19	0.05	0.37	0.22	0.66	1.27
2001–2003							
Stat/coll.(15)	548	6,255	64	2,222	1040	13,790	1,103
SHHD (16)	27	5,366	66	2,171	863	7,392	374
(15)/(16) – 1	19.3	0.17	−0.04	0.02	0.20	0.87	1.95
1992–2003							
Stat/coll. (17)	396	5,798	77	2,262	945	11,465	709
SHHD (18)	23	4,898	83	1,961	732	5,279	236
(17)/(18) – 1	16.1	0.18	−0.07	0.15	0.29	1.17	2.00

Note: Concentrate feed is split into grains and other feed. Capital includes depreciation, fixed asset repair and maintenance, and small tool purchase and is measured simply in present price.
Source: Agricultural Commodity Production Cost and Return Survey Handbooks, 1993–2004.

higher grain inputs per cow than either of the low-yield areas, but this is not always the case for the other inputs. The concentrate feed-to-output ratio is lower for Kunming but higher in the case of Nanning, compared with those in the high-yield areas. Clearly, little can be concluded about suburban dairy farm productivity across cities in China in the absence of further analysis.

6. Methodology and estimation

Over the last 20 years, the literature on productivity measurement has been extended from the standard index-number calculation of TFP toward more refined decomposition methods. In the simple TFP framework, the growth rate of this index is usually interpreted as a measure of technical change, but this interpretation incorporates several restrictive assumptions, such as constant returns to scale and allocative and technical efficiency. More recently, distance functions have been used in attempts to overcome some of these shortcomings and to identify the components of productivity change (Coelli and Perelman, 2000). This approach does not require any behavioral assumptions, such as cost minimization or profit maximization, to provide a valid representation of the underlying production technology (Brümmer et al., 2002). In this analysis of productivity in China's dairy industry, we employ the input distance function methodology.

Table 2
Variations in farm size, yields, and major inputs per cow across cities in China (2003)

Suburban areas	Location[a]	Farm size (head)	Yield (kg)	Labor (day)	Grains (kg)	Other fine feed (kg)	Fodder (kg)	Capital (Yuan)
Suburban state-collective dairy farms								
Zhengzhou	Center	220	3,878	49	1,320	1,180	13,000	399
Guangzhou	South	330	4,000	36	2,530	1,280	10,800	1,210
Guiyang	Southwest	3,400	5,500	90	3,096	4	16,500	1,865
Lanzhou	West	330	5,949	24	2,156	817	12,423	963
Xining	West	594	6,125	58	1,948	1,947	16,229	573
Hangzhou	Southeast	882	6,414	75	2,966	817	17,642	518
Changchun	Northeast	380	6,540	132	3,078	720	12,521	324
Hefei	Southeast	902	6,667	73	1,324	567	15,888	909
Jinan	East	1,184	6,750	15	3,429	605	12,962	2,203
Wuhan	Center	3,500	6,940	65	2,430	1,050	12,900	1,184
Shijiazhuang	North	147	7,044	74	1,450	1,450	17,683	1,687
Shanghai	East	216	7,494	55	2,722	1,173	17,400	875
Wulumuqi	Far east	1,138	7,939	50	2,259	1,506	11,805	3,201
Beijing	North	512	8,421	24	2,154	2,342	5,423	952
Suburban specialized household dairy farms								
Kunming	Southwest	11	3,770	43	1,000	557	3,696	175
Nanning	South	9	4,424	42	1,553	1,650	9,256	258
Xian	West	2	4,861	118	2,080	367	1,399	182
Changsha	South	15	4,900	59	2,800	700	2,480	1,450
Qingdao	East	3	5,000	68	1,784	957	5,127	238
Yinchuan	West	43	5,116	17	3,598	1,136	4,779	167
Zhengzhou	Center	8	5,169	66	1,625	765	10,000	356
Chengdu	Southwest	17	5,290	61	2,151	944	19,599	291
Harbin	Northeast	6	5,334	91	2,803	91	3,467	736
Taiyuan	Center	9	5,362	70	1,630	1,630	12,000	270
Shenyang	Northeast	30	5,705	39	1,422	356	10,160	66
Huhehaote	North	12	6,003	56	2,274	1,048	6,955	96
Jinan	East	8	6,169	77	2,469	675	9,280	339
Beijing	North	171	6,409	38	2,368	971	6,630	422
Tianjin	North	152	6,454	42	2,252	1,051	9,664	220

Source: Agricultural Commodity Production Cost and Return Survey Handbooks 2004.

We also assume that this input distance function can be approximated by the translog functional form. The homogeneity restrictions are imposed by choosing the quantity of one of inputs as *numeraire* (here it is number of cows per farm). We define technical inefficiency as a function of both time and locational dummy variables. Details of this type of model and its estimation can be found in Coelli and Perelman (2000), Karagiannis et al. (2004), and Khumbakar and Lovell (2000).

There are serious econometric problems with two-stage formulation estimation (Khumbakar and Lovell, 2000, p. 264); therefore, we use the FRONTIER 4.1 computer program developed by Coelli (1996) to estimate the stochastic frontier function and technical inefficiency models simultaneously as in Coelli and Perelman (2000) and Paul et al. (2000). We then decompose productivity growth into technical change and efficiency components, as in Karagiannis et al. (2004).

The input distance function is estimated using the suburban farm panel data, and again with the panel of data for the dairy sector as a whole. This will permit us to say something about whether or not productivity growth has been more rapid on suburban dairy farms than on those in rural locations. Should productivity growth be shown to be faster on suburban farms than for the whole industry, for example, then it must also have been faster than on the nonsuburban dairy farms.

A concern with the estimation of distance functions is that the normalized inputs appearing as regressors may not be exogenous. In fact, the ratio model we adopt is less susceptible of input endogeneity bias than the normal model (Brümmer et al., 2002). Schmidt (1988) and Mundlak (1996) have also examined variables in ratio form and found that the ratio of two input variables does not suffer from endogeneity assuming expected profit maximization. Another concern is that our model does not include any environmental variables. While the majority of dairy cows in China, especially in the case of suburban dairy farm system, are farmed in housed facilities, so that productivity and performance may not be influenced by weather conditions to the extent that might occur in grazing systems, such influences may still be present. Thus our estimates of technical efficiency may be subject to downward bias, especially for the entire dairy industry because it also includes grazing systems.

Table 3
The estimates of input distance function for suburban dairy farms in China

Variables in log format	Pooled data		State and collective		Specialized household	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Y_1	−0.137	−0.70	−0.622	−4.29	1.049	2.47
Y_2	−0.165	−1.23	−0.142	−0.92	−0.326	−1.07
X_2	0.525	1.65	−0.988	−2.23	2.552	4.54
X_3	−0.055	−0.15	−0.913	−5.77	1.994	2.24
X_4	0.220	1.11	0.379	0.97	1.009	4.43
X_5	−0.566	−2.33	−0.108	−0.36	−1.866	−3.66
$Y_1Y_1/2$	0.028	1.93	0.034	2.19	−0.009	−0.24
Y_1Y_2	−0.001	−0.12	−0.002	−0.17	−0.003	−0.13
$Y_2Y_2/2$	−0.003	−0.38	−0.008	−1.21	0.003	0.13
$X_2X_2/2$	−0.028	−1.42	0.016	0.79	−0.138	−2.21
X_2X_3	0.056	1.57	0.120	3.06	−0.130	−1.97
X_2X_4	−0.055	−3.00	−0.018	−1.01	−0.037	−1.14
X_2X_5	0.048	2.56	0.032	6.77	0.206	5.07
$X_3X_3/2$	0.034	0.80	−0.012	−0.37	0.074	0.84
X_3X_4	0.023	1.14	0.050	1.77	−0.091	−2.52
X_3X_5	0.034	1.31	0.035	1.69	0.066	1.39
$X_4X_4/2$	0.016	0.83	−0.050	−1.52	−0.008	−0.36
X_4X_5	−0.001	−0.07	0.003	0.20	0.041	3.27
$X_5X_5/2$	0.082	4.54	0.019	0.90	−0.058	−2.01
Y_1X_2	−0.032	−1.97	0.008	0.39	−0.121	−3.14
Y_1X_3	−0.070	−3.50	−0.041	−2.21	−0.127	−2.45
Y_1X_4	−0.017	−1.40	−0.024	−1.48	−0.051	−2.32
Y_1X_5	−0.050	−4.16	−0.039	−3.15	0.020	1.21
Y_2X_2	−0.018	−1.79	−0.019	−2.09	−0.008	−0.34
Y_2X_3	0.009	0.66	0.029	2.26	−0.023	−0.63
Y_2X_4	0.001	0.09	0.002	0.24	0.055	3.88
Y_2X_5	0.026	2.73	0.009	0.82	0.010	0.84
t	−0.001	−0.02	−0.350	−3.55	0.128	1.07
$tt/2$	0.004	2.59	0.000	0.31	0.016	6.50
tY_1	0.000	0.18	−0.001	−0.27	0.004	0.58
tY_2	0.001	0.78	0.002	0.90	−0.007	−1.84
tX_2	−0.002	−0.51	0.004	0.91	−0.029	−2.74
tX_3	0.007	1.26	0.020	2.53	0.013	1.26
tX_4	−0.012	−3.30	0.015	2.17	−0.034	−7.65
tX_5	0.005	1.63	0.008	2.64	0.024	4.90
SHHD	0.097	2.29	–	–	–	–
Log *LF*	351.3	–	253.76	–	156.25	–
Observations	367	–	230	–	137	–
Parameters	37	–	36	–	36	–
Inefficiency model:						
Sigma-squared	0.011	181.8	0.008	5.71	0.010	6.36
Gamma	0.803	26.45	0.876	3.07	0.959	258.6
t	0.009	1.87	0.018	2.07	0.056	5.83

Note: Constant term and city dummies in the efficiency model were not displayed. X_1 is used as numeraire. Variables are milk output (Y_1), by-products (Y_2), labor (X_2), concentrate feed (X_3), fodder (X_4), and capital (X_5) All are expressed on a per cow (X_1) basis. t is a time trend.

7. Results and discussion

Model specification tests were undertaken to indicate whether the suburban state-collective farm data and that for the suburban specialized households could be pooled, and to compare the translog functional form with a Cobb–Douglas specification of the production frontier. Results are shown in Appendix A for the suburban sample. These provided statistically significant support for estimating separate models for suburban state-collective and specialized household farms, and for the use of the translog functional form.

The estimated coefficients of the translog input distance functions for the suburban farms are presented in Table 3. The pooled model assumes that all parameters except the intercept are identical for both farm types (columns 2 and 3). This was rejected by the test referred to above—note also the significance of the suburban specialized household intercept dummy variable. The separately estimated input distance functions for both suburban farm types are found to be well behaved in that, at the point of approximation, they are nonincreasing in outputs and nondecreasing in inputs (columns 4–7). The estimated variances of the one-sided error terms are 0.008 and 0.010 for suburban state-collective and specialized household farms, respectively, and the presence of technical inefficiency is related to the statistical significance of σ_u^2. Thus, a significant part of output variability among suburban dairy farms can be explained by differences in the degree of technical efficiency (Karagiannis et al., 2004).

The estimates of TFP growth and its decomposition into technical efficiency and technological change components for China's suburban dairies show a remarkably consistent story of a sector that is undergoing dynamic, yet disruptive, changes. Perhaps most typically we see that TFP in the dairy sector has increased over time, rising at 2.04% per year in the suburban specialized household sector (Table 4, row 1). This rate of TFP growth, internationally, is considered healthy (and above the rate of growth of the population, albeit in the case of dairy below the rate of growth of demand). This rate of growth of dairy TFP, in fact, is similar to the rates of growth of China's cropping TFP (Jin et al., 2002) and livestock (Rae et al., 2006).

The decomposition analysis clearly shows that technological change, not improvements to efficiency, has been the driver of the rise in productivity (Table 4, row 1, columns 5 and 6). In fact, in the suburban specialized household dairy sector technological change increased output by 4.96% per year. In other words, the adoption of new genetics, feeding regimes, and milking approaches has had a large impact on the suburban dairy sector. In contrast, disruptions caused by fast growth or the lack of training and understanding of changing dairy production and marketing processes, that might contribute to inefficiencies, have caused technical efficiency to fall over time, by 2.92% per year.

The suburban state-collective sector experienced almost identical contours in TFP, technological change and technical efficient, albeit the rates of changes were all somewhat attenuated (Table 5, row 1). TFP growth was slower in the suburban state-collective dairy sector, rising only 0.91% annually. Like the suburban specialized household sector, this growth rate was driven by technological change (2.57% per year) although this was less than the rate of technological change in the suburban specialized household sector. Similarly, TFP would have been higher had whatever affects the efficiency of the production environment not contributed to a 1.66 slowdown in productivity.

One of the most interesting observations from our city analysis (Table 4, rows 2–16; Table 5, rows 2–25) is that although there were differences among the sample cities (as one might expect in a nation as big and diverse as China), most of the trends for TFP and its two component elements—technological

Table 4
Decomposition of total factor productivity (TFP) into technical efficiency (TE) and technological change (TC) on suburban specialized household dairy farms in China

City	Period	Obs	TFP decomposition (%)		
			TFP	TE	TC
Mean[a]	1992–2003	12	2.04	−2.92	4.96
Tianjin	1992–2003	10	−0.62	−4.12	3.49
Taiyuan	1999–2003	5	1.86	−9.11	10.98
Huhehaote	1998–2003	6	7.01	−2.19	9.20
Shenyang	1992–2003	9	5.99	−0.10	6.09
Harbin	1992–2003	12	1.46	−5.59	7.05
Fuzhou	1995–2003	9	1.99	−5.25	7.24
Jinan	1995–2003	9	3.24	−3.33	6.57
Changsa	1998–2003	5	7.71	−7.23	14.94
Chongqing	1993–2003	8	−2.33	−2.14	−0.19
Chengdu	1996–2003	6	8.03	−3.86	11.89
Kunming	1994–2003	9	1.30	−3.77	5.07
Xian	1993–2003	9	1.04	−7.80	8.84
Yinchuan	1992–2003	11	2.11	−4.36	6.47
Qingdao	1993–2003	7	3.70	−6.15	9.85
Ningbo	1992–1997	5	−0.96	−0.26	−0.70

Note: (1) In order to evaluate the reliability of the results, we present the period and observations for each suburban city. It should be noted that the periods only give the starting and ending years of observations. (2) The table retains only those cities having five or more observations. (3) It can be observed that TC growth is generally much faster during the second half of study period than during the first half. So, comparisons of TC growth across cities should be done with due caution.
[a]Estimated at data means.

Table 5
Decomposition of total factor productivity (TFP) into technical efficiency (TE) and technological change (TC) on suburban state-collective dairy farms in China

City	Period	Obs	TFP decomposition (%)		
			TFP	TE	TC
Mean[a]	1992–2003	12	0.91	−1.66	2.57
Beijing	1992–2003	11	3.16	0.16	3.00
Tianjin	1992–2003	9	1.06	−1.63	2.69
Shijiazhuang	1992–2003	12	1.38	−1.29	2.67
Changchun	1992–2003	8	−1.58	−3.76	2.17
Harbin	1992–1996	5	−2.12	−2.56	0.45
Shanghai	1992–2003	12	1.26	−1.87	3.13
Nanjing	1992–2003	10	3.22	−0.07	3.29
Hangzhou	1996–2003	8	1.01	−3.10	4.11
Hefei	1992–2003	9	3.08	0.54	2.53
Jinan	1994–2003	10	0.09	−3.42	3.52
Zhengzhou	1992–2003	11	−1.98	−3.36	1.39
Wuhan	1994–2003	10	3.67	0.44	3.23
Guangzhou	1992–2003	9	−1.74	−4.61	2.88
Nanning	1992–2001	8	−3.01	−5.88	2.87
Chongqing	1992–2003	7	1.53	−1.20	2.73
Chengdu	1996–2001	5	3.42	−0.26	3.68
Guiyang	1992–2003	7	−0.15	−3.83	3.68
Kunming	1992–1999	7	0.88	−2.67	3.55
Xian	1992–2003	12	3.85	0.88	2.97
Lanzhou	1992–2003	8	2.47	−0.33	2.81
Xining	1993–03	11	0.00	−2.17	2.18
Wulumuqi	1996–2003	7	0.81	−3.05	3.86
Dalian	1994–2003	10	0.65	−2.01	2.66
Ningbo	1992–2003	11	0.04	−2.44	2.48

Note: See Table 4.
[a]Estimated at mean values of all variables.

change and efficiency—move in the same direction across the cities. For example, in the case of the suburban specialized household dairy sector, 12 out of 15 cities experience positive growth rates in TFP (Table 4, column 1). Of the 15 cities, 14 of them experienced positive growth from technological change (column 3) and negative growth from technical efficiency (column 2). The same robustness across cities holds for the suburban state-collective dairy sector as well (Table 5); 18 out of 24 sample cities experienced rising TFP; all 24 of them rose due to technological change; all but 3 (21 of 24) would have had higher productivity growth had there not been falling efficiency.

The average level of efficiency of the suburban specialized household farms falls from 0.82 in 1992 to 0.68 in 2003; those for suburban state-collective household farms fall about the same from 0.88 to 0.64 (Appendix B). This evidence makes us think that the falling efficiency, at least in part, is due to the rapid expansion of China's dairy herd size and that at least part of the inefficiency drop may expect to correct itself when this explosive growth abates somewhat. At the same time, it cannot be discounted that the fall in efficiency is occurring at a time when China's extension system is almost at its worst (Hu et al., 2004).

After running the same productivity analysis and decomposition on the full set of dairies in the SDPC's cost of production data set (i.e., including suburban and nonsuburban dairy farms—see Appendix C for the estimates), it is clear that the dairy sector in China's suburban regions at the very least appears to be more dynamic and in the midst of some disequilibrium (Table 6). The dynamism of the suburban dairy sector can be seen by its relatively higher rate of growth from technological change. The reductions in technical efficiencies, however, are also greater for the suburban dairies. Therefore, although in the past 10 years the two sectors—suburban and nonsuburban—have had somewhat similar rates of total productivity growth, in looking toward the future (assuming that recent rates of technological change will continue), the main challenge facing the suburban sector is to try to overcome the efficiency deterioration from which it has been increasingly suffering over the past few years.

Table 6 also demonstrates the relatively higher level of TFP growth that is enjoyed by specialized household dairy farms (row 1 for suburban dairy farms and row 2 for all dairy farms) when compared with state-collective dairy farms (row 3 for suburban dairy farms and row 4 for all dairy farms). The higher rate of TFP growth for specialized household dairy farms is generated in both cases by higher rates of technical change. We do not know for sure if historically (or even recently) the state-collective dairy sector has received more than its share of concessional loans and other support, but if it has, clearly one policy implication of this finding is that relatively more support should be directed at the specialized household sector if officials want to increase the rate of the sector's productivity rise.

Table 6
Comparisons of growth in productivity and its components, and technical efficiency across suburban and all dairy farms

Farm type	Annual TFP decomposition growth (%)			TE level	
	TFP	TE	TC	1992	2003
Specialized households					
Suburban	2.04	−2.92	4.96	0.88	0.64
All farms	2.33	0.78	1.55	0.82	0.90
State-collective					
Suburban	0.91	−1.66	2.57	0.82	0.68
All farms	0.25	−0.79	1.04	0.87	0.80

Note: The same methodology was used for both suburban and all dairy farms.

8. Conclusions and implications

The rapid growth in consumption of milk and other dairy products in China is very much an urban phenomenon. Given the current state of development of the milk-handling infrastructure in China, it is not surprising that milk production is increasingly concentrated near urban demand areas. New dairy farm developments, including the large-scale "concentration centers," have involved considerable national and international investment in modern facilities, technologies, and high-performing livestock. One of our conclusions is that technical change in the suburban milk sector has been more rapid than for the milk sector as a whole, and especially in the case of suburban specialist household farms. Another conclusion is that suburban milk producers, on average, have not been able to keep up with the rapidly advancing production frontier. While suburban dairy farms produced on average at 82–88% of potential in 1992, this had fallen to less than 70% by 2003. Evidently, the successful adoption of new technologies has not been evenly spread throughout the suburban industry, with the slow adopters and nonadopters falling behind. The low technical efficiency on suburban dairy farms is probably also influenced by the fact that milk production has been expanding rapidly around suburban areas during the last decade. In such an environment of new dairy farm developments and rapidly increasing input use, a lot of experimentation and perhaps mistakes by new farmers in the search for new technologies should not be too surprising. Positive and often rapid technical change coupled with negative efficiency growth was also a common finding across cities. Such an outcome is also likely where government priorities and policies favor certain localities and farm types over others for new investments.

There appears to be considerable scope for improving suburban dairy farm performance by increasing the efficiency of producers. Attention to the use of best practice techniques for given technologies and diffusion of modern successful technologies across more suburban areas would appear to be priorities if average TFP growth is to more closely approach the rate of growth in technical change. While part of the inefficiency (as we argue) may be just a function of the dynamism of the sector (which we do not want to see disappear), more attention to extension and the development of more appropriate technologies might help mitigate some of the inefficiencies (even during times of rapid growth) which could turn into higher levels of productivity growth.

There are many factors contributing to variations in TFP growth and its components across cities that we were not able to explicitly incorporate in our analyses. These include information on the breed composition of dairy herds, the influence of local and central government policies on credit and investment, local climatic conditions, and the nature of available roughage resources. Had data been available to construct suitable variables, some of these could have been included in the efficiency model—in their absence, we had to use city dummy variables. We should also repeat our earlier warning that the omission of climatic variables could have caused a downward bias in our technical efficiency estimates.

While the dynamism of the suburban sector is apparent from our analysis, when we track the very recent trends in processing plant expansion, we can detect what appears to be a shifting pattern. Instead of moving in towards the middle of the concentrated urban areas and immediate suburbs, the map of new dairy processing centers after 2000 show that they have dispersed both to the far suburbs and to neighboring, more remote prefectures and counties (Fig. 1, Panel C). Clearly, the rise of large processing plants is occurring despite the dynamism of the suburban dairy sector.

After seeing these trends in our data, we visited a number of suburban farmers, processors, and government officials and discovered that indeed while they recognize the economies of concentrating dairy production closer to large cities, other forces are starting to work against suburban dairies. First, as China develops, its land, labor, and other factor prices near the city are rising faster than factor prices in more remote areas. Second, as China has developed its infrastructure and communications, there is less friction in distance. This is especially true when noting that so much of China's new dairy consumption is occurring in the form of yogurt and UHT milk, less perishable products that place lower demands on processors to get their product to city consumption centers fast. Finally, there has begun to be a realization that large concentrated livestock-based industries can be highly pollutive, especially when placed in close proximity to large urban residential and industrial concentrations. As a consequence, for the first time in recent years, large cities are beginning to question the attractiveness of having a dairy industry so close to the city and have begun to pass regulations to try to curb the location of new production and processing in the immediate location of the large cities. While we do not know the extent to which this is influencing the shift of plant location, it most likely plays a significant role. Hence, while there are many economic forces over the past two decades that have emerged to begin to take the cows to town, at the very time that they are becoming established there, equally powerful forces appear to be getting ready to escort them back out. Only time will tell which forces will win . . . and when.

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Appendix A. Maximum likelihood ratio tests for splitting suburban specialized household dairy farms and suburban state-collective dairy farms (LR test 1) as well as C-D function vs. translog function (LR test 2)

Restricted function	Likelihood function		# of restrictions	χ^2 statistics
	Unrestricted	Restricted		
LR test 1:	392.78	351.30	35	82.9***
LR test 2:				
Specialized household	156.25	75.18	28	162.1***
State and collective	253.76	228.75	28	50.0***

Note: ***stands for 1% significance level.

Appendix B. The change of technical efficiency (TE) on suburban dairy farms in China

State-collective				Specialized households			
City	1992–2003	1992	2003	City	1992–2003	1992	2003
Mean[a]	0.76	0.82	0.68	Mean[a]	0.80	0.88	0.64
Beijing	0.95	0.98	0.97	Tianjin	0.81	0.94	0.57
Tianjin	0.86	0.98	0.82	Taiyuan	0.75	–	0.67
Shijiazhuang	0.86	0.89	0.77	Huhehaote	0.91	–	0.87
Changchun	0.80	0.78	0.71	Shenyang	0.87	0.96	0.71
Harbin	0.79	0.85	–	Harbin	0.66	0.91	0.49
Shanghai	0.88	0.98	0.80	Fuzhou	0.71	–	0.60
Nanjing	0.66	0.89	0.65	Jinan	0.84	–	0.75
Hangzhou	0.79	–	0.67	Changsa	0.55	–	0.43
Hefei	0.71	0.72	0.74	Chongqing	0.84	*0.98*	0.70
Jinan	0.76	–	0.67	Chengdu	0.76	–	0.57
Zhengzhou	0.52	0.72	0.51	Kunming	0.67	*0.75*	0.56
Wuhan	0.67	–	0.61	Xian	0.76	*0.98*	0.53
Guangzhou	0.56	0.72	0.48	Yinchuan	0.76	0.80	0.54
Nanning	0.63	0.75	*0.53*	Qingdao	0.79	*0.98*	0.68
Chongqing	0.69	0.73	0.63	Ningbo	0.99	0.99	–
Chengdu	0.78	–	*0.73*				
Guiyang	0.58	0.71	0.53				
Kunming	0.77	0.75	*0.67*				
Xian	0.93	0.79	0.88				
Lanzhou	0.70	0.83	0.68				
Xining	0.74	*0.84*	0.67				
Wulumuqi	0.89	–	0.78				
Dalian	0.73	*0.74*	0.62				
Ningbo	0.75	0.82	0.66				

Note: The numbers in italics are not in the year shown but either after the earlier or subsequent years to demonstrate the trend of technical efficiency change over time. The table only keeps those that have five-year or over observations.

[a]Simple unweighted means of all available regions.

Source: Model results.

Appendix C. The estimates of input distance functions for all dairy farms in China

Variables in log format	State-collective		Specialized households	
	Coefficient	*t*-ratio	Coefficient	*t*-ratio
Y_1	−0.598	−1.57	2.499	5.15
Y_2	−0.491	−2.17	−2.087	−5.53
X_2	−0.180	−0.38	3.087	6.16
X_3	−1.118	−1.72	1.880	4.88
X_4	0.644	1.24	−0.619	−2.46
X_5	−0.091	−0.23	−1.009	−2.35
$Y_1Y_1/2$	0.110	4.87	0.069	4.73
Y_1Y_2	−0.021	−2.02	−0.066	−4.53
$Y_2Y_2/2$	0.005	0.74	0.067	4.95
$X_2X_2/2$	−0.074	−2.97	−0.562	−8.81
X_2X_3	0.052	0.88	−0.013	−0.19
X_2X_4	0.079	1.94	0.067	3.45
X_2X_5	−0.027	−1.03	0.246	4.86
$X_3X_3/2$	0.057	0.74	0.015	0.20
X_3X_4	0.094	1.64	−0.015	−1.19
X_3X_5	0.063	1.63	0.030	0.71
$X_4X_4/2$	−0.088	−2.07	−0.007	−0.73
X_4X_5	−0.040	−1.51	−0.007	−0.68
$X_5X_5/2$	0.046	1.81	−0.098	−4.18
Y_1X_2	−0.030	−0.86	−0.198	−8.23
Y_1X_3	−0.087	−2.30	−0.431	−7.59
Y_1X_4	−0.074	−3.61	0.074	14.07
Y_1X_5	−0.014	−0.97	0.014	0.78

(Continued)

Appendix C. *Continued*

Variables in log format	State-collective		Specialized households	
	Coefficient	t-ratio	Coefficient	t-ratio
Y_2X_2	0.008	0.50	0.021	0.91
Y_2X_3	0.042	1.86	0.309	8.22
Y_2X_4	0.036	2.81	−0.039	−3.02
Y_2X_5	−0.001	−0.15	0.016	1.33
T	−0.036	−0.46	0.046	0.59
$tt/2$	−0.005	−2.91	−0.005	−3.48
tY_1	−0.010	−2.52	−0.017	−4.26
tY_2	0.003	1.12	−0.005	−1.21
tX_2	−0.019	−3.16	−0.062	−12.83
tX_3	0.008	0.74	0.054	4.68
tX_4	0.019	3.13	0.005	1.18
tX_5	0.005	0.93	0.008	1.53
Log LF	176.44	–	143.08	–
Observations	194	–	120	–
Parameters	36	–	36	–
Inefficiency model				
Sigma-squared	0.011	10.06	0.021	9.74
Gamma	0.405	7.67	0.991	105.86
t	0.000	4.96	0.001	0.22

Note: Constant term and province dummies in the efficiency model were not displayed. X_1 is used as numeraire.

Appendix D. Decomposition of total factor productivity (TFP) into technical efficiency (TE) and technological change (TC) on all specialized household dairy farms in China

Province	Period	Obs	TFP decomposition (%)		
			TFP	TE	TC
Mean[a]	1992–2003	12	2.33	0.78	1.55
Tianjin	1992–2003	12	1.39	0.84	0.55
Hebei	1992–2003	12	4.57	1.45	3.12
Shanxi	1993–2003	4	5.51	−0.26	5.77
Neimeng	1992–2003	10	−2.11	−0.38	−1.73
Liaoning	1994–2003	6	3.06	0.43	2.63
Jilin	1992–1999	4	−6.34	−7.28	0.94
Heilongjiang	1994–2003	10	0.06	0.04	0.03
Anhui	1992–2003	4	3.26	−2.10	5.36
Fujian	1996–2003	7	−3.65	−3.13	−0.52
Shandong	1997–2003	7	2.70	−0.92	3.62
Henan	1993–2003	11	1.10	0.14	0.96
Hunan	2000–2003	5	1.80	0.54	1.26
Chongqing	2000–2003	4	0.80	−1.76	2.56
Sichuan	2000–2003	3	−3.00	−4.37	1.37
Yunnan	2000–2003	4	−1.59	−0.28	−1.31
Shaanxi	1993–2003	9	−1.33	−2.04	0.71
Ningxia	2000–2003	4	8.23	−2.32	10.54
Xinjiang	1997–2003	4	8.34	5.15	3.20

Note: In order to evaluate the reliability of the results, we present the period and observations for each province. It should be noted that the periods only give the starting year and ending year of observations. When estimating the model, we dropped Beijing, Shanghai, Zhejiang, Jiangxi, and Guanxi because they have less than three observations.

[a]Estimated at data means.

Appendix E. Decomposition of total factor productivity (TFP) into technical efficiency (TE) and technological change (TC) on all state-collective dairy farms in China

Province	Period	Obs	TFP decomposition (%)		
			TFP	TE	TC
Mean[a]	1992–2003	12	0.25	−0.79	1.04
Beijing	1992–2003	12	1.41	0.00	1.41
Tianjin	1992–2003	8	1.49	−0.70	2.19
Hebei	1992–2003	12	0.36	−0.19	0.55
Neimeng	1992–1997	3	2.13	0.00	2.12
Liaoning	1995–2003	7	−1.00	−0.43	−0.56
Jilin	1992–2003	8	−0.03	0.06	−0.09
Shanghai	1992–2003	12	1.42	−0.05	1.47
Jiangsu	1992–2003	10	0.69	0.28	0.41
Zhejiang	1998–2003	6	0.17	0.55	−0.38
Anhui	1993–2003	11	−0.37	−0.10	−0.28
Fujian	1996–2003	4	−0.22	0.12	−0.34
Shandong	1992–2003	12	0.79	−1.46	2.25
Henan	1992–2003	12	−0.81	−1.58	0.77
Hubei	1992–2003	11	−0.10	−0.81	0.71
Hunan	1992–1997	4	−2.17	−1.39	−0.78
Guangdong	1993–2003	8	0.09	−1.90	1.99
Guangxi	1995–2003	8	−1.72	−1.26	−0.45
Hainan	2000–2003	4	0.35	−0.65	1.01
Chongqing	1997–2003	6	−0.75	−1.15	0.41
Guizhou	1992–2003	5	−1.10	0.05	−1.15
Shaanxi	1992–2003	8	5.13	2.67	2.46
Gansu	1992–2003	11	0.60	−1.29	1.89
Qinghai	2000–2003	4	−0.54	−0.50	−0.04
Xinjiang	1993–2003	8	0.46	−0.03	0.49

Note: See Appendix D. When estimating model, we dropped Jiangxi, Sichuan, Yunnan, and Ningxia because they have less than three observations.

[a]Estimated at data means.

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