The Rapid Rise of China's Dairy Sector: Factors Behind the Growth in Demand and Supply

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Abstract

With the rapid growth in China's dairy industry, a number of recent papers have addressed either the supply or the demand trends for dairy products in China. None, however, presents a systematic explanation for the recent growth in both the supply and demand for dairy products. The goal of this paper is to sketch a more comprehensive picture of China's dairy sector and to assess the nature of the sector's development in the coming decades. Drawing upon several empirical studies, we examine the trends in dairy product consumption to create a composite picture of the factors underlying the recent growth. We also empirically investigate the sources of production gains in milk supply and assess the relative importance of expanding herd size, changes in the nature of production, technological change, and improvements in efficiency to the overall growth of milk production.

Keywords: China, consumption, dairy, milk supply, stochastic production frontier, total factor productivity.

THE RAPID RISE OF CHINA'S DAIRY SECTOR: FACTORS BEHIND THE GROWTH IN DEMAND AND SUPPLY

In the early 1990s, more than a decade after China's emergence from its period of Socialist isolation, Garnaut and Ma (1993) noted that the nation's food demand patterns were emerging in ways that were largely consistent with other East Asian nations. Food grain demand was growing slowly but was not expected to expand greatly in the succeeding years because of low income elasticities. The demand for fruit, fish, and meat was beginning to accelerate in urban areas and was expected to continue to rise rapidly over the rest of the 1990s and beyond. While Garnaut and Ma's focus was on estimating China's actual income level and not on predicting food consumption patterns, the comparisons they made with past experiences in Japan, Korea, Taiwan, Hong Kong, and Singapore provided a remarkably consistent framework through which China's future consumption trajectory could be discussed and understood. In fact, during the subsequent decade, China's food consumption patterns generally evolved in a manner consistent with the authors' comparisons to Taiwan.

In their discussion, Garnaut and Ma noted that dairy was the one commodity group in which China's development deviated from the trends displayed in other Asian countries. In the early 1990s, China's dairy consumption was absolutely low in both the urban and rural economies. The average urban resident in 1990 only consumed 7.51 kilograms per capita, roughly half of the quantity reported for Taiwan in the early 1970s.[1] The typical rural resident consumed far less, only 2.51 kilograms per capita. Even considering China's low income level and low levels of urbanization, overall consumption of dairy products in China seemed to be below what it should have been. However, it was unclear what was holding back the demand for dairy products. Garnaut and Ma postulated that "different tastes associated with historical contact with international consumption patterns" was the cause for the unusually low consumption of milk in China;[2] however, we suggest that historical preferences are only one of several factors influencing dairy demand.

Since the mid-1990s the lethargy of China's dairy sector has disappeared. Demand, especially in urban areas, has exploded (Zhou, Tian, and Zhou 2002; Yang, MacAulay, and Shen 2004). Those working on the rise of supermarkets (Reardon et al. 2004; Hu, Fuller, and Reardon 2004), school milk programs (Griffin 2004), and marketing cooperatives (Shen et al. 2005) have all noted the newly emerging role of dairy products. China's production of dairy products has risen sharply, albeit frequently in erratic and novel ways (World Bank 2005), and internationally there is a scramble to understand the implications of China's emerging dairy sector for future world trade.

While a number of papers have appeared recently that address either the supply or demand trends for dairy products in China (Zhou, Tian, and Zhou 2002; Yang, MacAulay, and Shen 2004; Fuller, Beghin, and Rozelle 2004; Fuller et al. 2004; Hu, Fuller, and Reardon 2004), we believe that the literature is still missing research that systematically explains the reasons for the recent rise of demand and discusses future demand expectations. Even more so, the current literature does not provide empirical analysis of the factors that have facilitated recent production growth or which factors will hinder or enable the domestic industry to supply China's growing demand for dairy products in the coming years.

The goal of this paper is to sketch a more comprehensive picture of China's dairy sector and to assess the nature of the sector's development in the coming decades. First, we examine the trends in dairy product consumption in China and draw upon the growing number of empirical studies to create a composite picture of the factors underlying the explosion in dairy consumption. Next, we investigate the sources of production gains that have supplied much of the recent rise in demand. We assess the relative importance of expanding herd size, changes in the nature of production, technological change, and improvements in efficiency to the overall growth of milk production. Based on our analysis of both supply and demand, we conclude with our perspective on the future path of dairy supply and demand in China and the role of international trade.

Dairy Demand

Much has been written in recent years about the rapidly changing diets of consumers in urban China (Hsu, Chern, and Gale 2001; Guo, Mroz, and Popkin 2000; Ma and

Popkin 1995). In general, urban consumers have increased the share of calories in their diets that come from animal fats and proteins, decreased intake of carbohydrates, and increased consumption of sugar and vegetable oils. Between 1985 and 2003, per capita consumption of grain and vegetables in urban China has declined by 40 percent and 18 percent, respectively. Over the same period, consumption of pork, beef and mutton, poultry, and aquatic products rose 22, 82, 164, and 57 percent, respectively. In addition to the changes in dietary composition, as incomes have risen, a greater share of food expenditures have been allocated to highly processed or prepared foods consumed away from home (Ma, Huang, and Rozelle 2005). Strangely, despite the obvious changes in meat and grain consumption patterns, fluid milk consumption in urban areas was fairly stable, at roughly 5 kg per person from 1985 to 1994. Since 1995, however, dairy consumption in urban China has grown annually at double-digit rates.

Table 1 displays urban dairy product consumption by income group based on data gathered in the National Bureau of Statistics's annual urban household expenditure survey. The data show clearly that dairy product consumption has increased at all income levels for the three product categories reported. Even households in the lowest 10 percent of the income distribution more than doubled their milk consumption in seven years. Fresh product (primarily milk) consumption increased nearly 300 percent or more for higher income groups. Although yogurt consumption was lower than milk powder consumption for all income groups in 1996, yogurt purchases grew roughly 29 to 37 percent annually, while milk powder consumption grew less than 7 percent annually. Unlike milk and yogurt, the growth rate for milk powder consumption decreased from low income to high, and milk powder consumption per capita for the highest income group grew just 6.7 percent over the seven-year period and actually declined in 2002 and 2003. There is some empirical evidence that milk powder is an inferior good for some demographics in China (Fuller, Beghin, and Rozelle 2004)

The growth in household incomes has played a major role in the rapid increase in dairy product consumption, but it cannot fully explain the changes that have occurred. Table 2 shows per capita nominal incomes and real income growth from 1996 to 2003 by income group. The growth in dairy product consumption shown in Table 1 only loosely corresponds to growth in real incomes While growth in real income generally matches the pattern of dairy product consumption growth across incomes groups (i.e., larger changes in income generate greater growth in consumption), the increases in consumption for the lower-income groups are much larger than one would expect, even from a luxury food item. Several recent studies using cross-sectional household data have attempted to estimate price and income elasticities for dairy products. Table 3 summarizes the findings for six studies. One of the most striking observations is that all of the studies to date suggest that milk and other dairy products are not elastic with respect to total household income. However, with respect to the household's allocation of food expenditures, dairy products typically represent one of the most elastic categories in the food basket.

TABLE 1. Annual urban dairy product consumption per capita by income group

	1996	1997	1998	1999	2000	2001	2002	2003
				kilograms per person				
Fresh Products								
Lowest 10%	2.52	2.62	2.87	3.34	4.59	5.61	4.83	6.71
Second Quintile	3.93	4.10	4.95	6.52	8.27	9.69	11.78	15.51
Third Quintile	4.84	4.97	6.17	7.62	9.83	11.78	15.79	18.94
Fourth Quintile	5.62	6.18	7.48	9.69	11.95	14.79	19.99	23.43
Top 10%	7.91	9.02	10.66	13.78	17.52	19.60	26.46	28.29
Average	4.83	5.07	6.18	7.88	9.94	11.90	15.72	18.62
Yogurt								
Lowest 10%	0.11	0.15	0.28	0.39	0.51	0.55	0.51	0.68
Second Quintile	0.23	0.34	0.48	0.65	0.88	1.10	1.35	2.01
Third Quintile	0.33	0.44	0.57	0.80	1.09	1.30	1.76	2.57
Fourth Quintile	0.34	0.58	0.8	1.14	1.42	1.69	2.30	3.11
Top 10%	0.56	0.78	1.16	1.47	1.47	2.27	3.31	4.33
Average	0.32	0.44	0.64	0.87	1.12	1.36	1.80	2.53
Milk Powder								
Lowest 10%	0.22	0.23	0.24	0.25	0.26	0.29	0.34	0.31
Second Quintile	0.37	0.37	0.4	0.40	0.43	0.46	0.57	0.57
Third Quintile	0.42	0.40	0.43	0.47	0.52	0.52	0.58	0.61
Fourth Quintile	0.47	0.46	0.5	0.52	0.56	0.56	0.59	0.62
Top 10%	0.59	0.61	0.6	0.62	0.7	0.74	0.65	0.63
Average	0.41	0.41	0.43	0.44	0.49	0.50	0.60	0.56

TABLE 2. Annual per capita nominal income by income group (yuan)

	Lowest 10%	Second Quintile	Third Quintile	Fourth Quintile	Top 10%	Average
1996	2454	3780	4580	5599	9250	4845
2003	2762	5706	7754	10464	23484	9061
Percent change in real income	9.7	47.2	65.1	82.2	147.5	82.3

TABLE 3. Elasticity estimates for dairy products

Study	Data	Commodity	Own Price	Expenditure	Income
Fuller, Beghin, and Rozelle 2004	2001 survey data from Beijing, Shanghai, and Guangzhou	Milk			0.366
		Yogurt			0.135
		Milk Powder			-0.084
		Ice Cream			0.190
Ma, Rae, Huang, and Rozelle 2004	Adjusted CNBS expenditure survey data from 1991-2001	All Dairy	-1.191	1.144	
Wang, Zhou, and Yang 2004	1999 survey data from Jilin, Inner Mongolia, Shandong, Jiangsu, Sichuan, and Guangdong	Milk			0.320
Liu and Chern 2003	1998 CNBS expenditure survey data from Shandong, Jiangsu, and Guangdong	Milk	-1.066	1.055	0.657
		Yogurt	0.993	0.963	0.600
Zhang and Wang 2003	1998 CNBS survey data for 30 major cities	All Dairy	-1.074	1.190	0.381
		Milk	-1.199	1.295	0.271
		Yogurt	-0.861	0.867	0.182
		Milk Powder	-0.807	0.583	0.122
Gould and Dong 2004	2001 CNBS expenditure survey data from Henan Jiangsu, Guangdong Shandong, and Heilongjiang	All Dairy	-0.405	1.191	

All of the income elasticity estimates in Table 3 were computed using data for a single year, so the impacts of shifts in preferences over time on income elasticities are not captured. Using a panel data set, Guo, Mroz, and Popkin (2000) have found evidence that income elasticities in urban China changed from year to year, with increasing elasticities for livestock products and decreasing elasticities for grains. Similarly, Huang and Bouis (2001) found empirical support for the idea that dietary changes in Taiwan in the 1980s were driven by changing lifestyles, changing occupations, and advances in the marketing system, as well as price and income factors. Without a doubt, the rapid growth in household incomes has been necessary to make dairy products affordable for Chinese households, but the development of China's economy and the opening of society to the West over the last two decades have prompted several other transformations that almost certainly facilitated growth in dairy product consumption.

Although we are not able to precisely quantify the source of demand change, we believe the current literature and our observations in the field show that there are at least three important sources of change, especially in urban China, that have played an integral role in shaping dairy demand: (a) changes in consumer perceptions of dairy products; (b) food purchasing behavior; and (c) dairy product marketing. Historically, the majority of Chinese have viewed milk as a nutritious food supplement, particularly for infants and the elderly (Zhou, Tian, and Zhou 2002; Glosser 1999), but milk has not been perceived as a food for regular consumption by the general population. These traditional perceptions are being challenged on several fronts. For example, current government guidelines for food and nutrition include regular milk consumption in their dietary recommendations. In a survey conducted in 2001, Fuller et al. (2004) found that more than 25 percent of 314 households surveyed in Beijing, Shanghai, and Guangzhou reported that a healthcare professional had recommended regular milk consumption. The expansion of television and radio ownership in the last decade has greatly increased the influence of the mass media and advertising on consumer perceptions. Television advertisements extolling the convenience, good taste, and healthiness of regular milk and yogurt consumption have become commonplace on China's networks. The same survey discussed in Fuller et al. (2004) found that 93 percent of the sample had seen television advertisements for milk products, and 73 percent had seen billboards with dairy product ads. Finally, the adoption of school milk programs in several large cities is sending the message to families with young children that milk consumption is important for the next generation.

The proliferation of nutrition information and positive messages promoting milk consumption can be viewed as an increase in the education level of the general population concerning dairy products. Equally important is the idea that the mass media is exposing many of China's households to foreign ideas, products, and lifestyles without citizens having to travel abroad. Inasmuch as this increased awareness of dairy products fosters a culture of dairy consumption, we can expect a growing percentage of households in China to integrate dairy products into their daily diets. Indeed, there is empirical evidence that education and travel are positively related to dairy product consumption (Fuller, Beghin, and Rozelle 2004; Bhandari and Smith 2000; Wang, Zhou, and Yang 2004).

Economic prosperity in China also is gradually changing lifestyles among urban households, and this, in turn, is affecting consumption patterns. Social policies enacted to slow population growth have reduced the number of children in modern urban families. With greater opportunities to find employment outside the home, the cost of spending time shopping and preparing food has risen, and an increasing number of China's households are willing to pay for prepared foods and packaging that increase shelf life and reduce shopping frequency. Many convenience foods—including packaged milk, yogurt, and ice cream—are frozen or chilled and require refrigeration until they are consumed. Thus, purchases of these products would undoubtedly be influenced by whether or not the household owned a refrigerator. Indeed, Gilmour (1998) suggests that refrigerator ownership should have a positive impact on dairy product consumption, and Lyon and Durham (1999) find empirical support for this hypothesis.

In their study of shopping patterns in Nanjing, Veeck and Veeck (2000) identified three general shopping behaviors among urban households: convenience shoppers, traditional shoppers, and frequent shoppers. Convenience shoppers accounted for 17 percent of the authors' sample. These households tend to eat outside the home frequently, purchase substantial amounts of convenience food (frozen, canned, or pre-cooked), shop only one or two times per week, and frequent several types of retail outlets. Convenience shoppers tend to be younger, have higher education levels, and have higher incomes than the sample average. Just under half of Veeck and Veeck's sample were traditional shoppers who purchase relatively little convenience food, seldom eat outside the home, and shop almost daily at a small number of retail outlets. These households tend to be older than the convenience shoppers and have substantially lower incomes. The rest of the households in the sample were frequent shoppers, whose shopping behavior is a hybrid of the other two groups. Frequent shoppers purchase food almost daily from a wide variety of retail outlets, and they do not eat out as often as the convenience shoppers. However, frequent shoppers often purchase convenience and packaged foods, including milk powder. This consumer segment has income levels that are comparable to those of convenience shoppers, but they are 10 years older on average.

This study of purchasing behaviors is interesting because it highlights the connection between income, product choices, and the variety of retail outlets shopped. These relationships are closely tied to the changes that can be observed in marketing of dairy products. Throughout the 1980s and into the 1990s, pasteurized milk was principally marketed through home distribution networks and specialized milk stores operated by the dominant local milk company (usually a state-owned milk producer and processor). This situation began to change in the early 1990s, as foreign dairy processors began investing in production facilities near key cities and as ultra high temperature (UHT) pasteurization technology was adopted by dairy processors in Inner Mongolia. Both of these developments prompted the introduction of new brands and products in urban dairy markets along China's eastern coast, sharpening the competition faced by incumbent firms.

New entrants to the market could not use the established distribution channels because they were owned and operated by the local dairy company. Consequently, entering firms channeled their products to consumers through other food retail outlets: street vendors, small grocery stores, and the newly emerging supermarkets and convenience stores. Recent papers point to the importance of supermarkets for dairy product purchases (Hu, Fuller, and Reardon 2004; Fuller et al. 2004; Fuller and Hu 2005). While home delivery networks still play an important role in pasteurized milk markets, surveys indicate that supermarket sales account for the majority of yogurt and UHT milk sales and a growing proportion of pasteurized milk sales (Fuller, Beghin, and Rozelle 2004; Fuller and Hu 2005). Consumers benefit from the expanded selection of products and brands available at supermarkets and from the frequent promotional discounts (Hu, Fuller, and Reardon 2004; Fuller and Hu 2005).

Another important development in the marketing of dairy products has been the creation of nationally recognized brands. When dairy product markets were local and segregated, branding was not important because usually only one or two companies existed in the market. Farmers or small processors that sold their products directly to consumers could develop a relationship with their customers, and the relationship substituted for brand identification. As dairy companies began to expand beyond their historical marketing regions into new markets, they needed to differentiate themselves from the local milk companies. More importantly, the companies needed to provide assurances of product quality and safety to consumers in the new markets. Unreliable quality and food safety concerns deterred some of China's consumers from purchasing milk in the past. Several of China's emerging national brands have successfully established credible reputations for quality and safety and consequently they command brand loyalty among many consumers. Marketing through supermarkets and convenience store chains can reinforce brand equity to the extent that consumers believe supermarkets choose the brands they carry based on product quality and value.

In sum, the rapid growth of dairy product consumption in China results from the convergence of several mutually reinforcing factors. Economic growth over the last two decades has prompted a shift in consumer preferences in urban areas toward meat, vegetable oils, fruits, and dairy products. Income alone, however, cannot explain the size of the increase in dairy product demand in the late 1990s. Information about the benefits of regular dairy product consumption provided by the government, the healthcare sector, and the dairy industry is convincing a growing number of China's consumers that milk is not just for children, the elderly, and the infirm. At the same time, the hectic pace of modern urban life promotes the consumption of prepared and packaged foods, including dairy products. Competition in China's dairy industry has forced dairy processors to adapt to the changes in consumer buying practices. Today, in a way that was inconceivable several years ago, dairy products can be found in a wide array of retail outlets. Supermarket and convenience store chains are bringing dairy products in greater numbers and varieties to a broader demographic of consumers, and the development of nationally recognized brands and ubiquitous use of mass media advertising is reducing the cost of searching for new consumers interested in adopting regular dairy consumption.

How will dairy product demand in China develop in the future? It is clear that consumption will continue to rise rapidly for a number of years. Much of the growth in milk and yogurt consumption in urban areas will likely come from the low- and middle-income segments of the population. As incomes continue to rise, consumption levels of these segments should approach those of the higher income brackets. Urban consumers in the higher income brackets are rapidly approaching consumption levels for milk and yogurt that are comparable to other medium- and high-income Asian countries. Consequently, growth of milk demand in these consumer segments will likely slow. At the same, there is still room for those in the highest income categories to expand total dairy product consumption. For example, wealthy households in China consume much less cheese than do consumers in Japan, Taiwan, or Korea; from this perspective, cheese demand still has substantial growth potential. Cheese consumption in China occurs chiefly through consumption of Western-style foods in restaurants (Fuller, Beghin, and Rozelle 2004), and further development of cheese consumption will likely follow the sales trends of pizza and other cheese-intensive restaurant foods.

In smaller cities and rural areas, many of the same factors that contributed to the explosion of dairy consumption in large urban areas are relevant for China's rural population as well. In fact, the dairy revolution has not even begun or is just beginning for many demographic groups. In particular, as incomes rise among other groups of consumers, including consumers in small cities and in rural areas, diets will shift toward increased consumption of livestock products (Ma and Popkin 1995). Supermarkets and convenience stores are gradually moving from large to medium and small cities. When these retail venues arrive, among other things, they will bring with them the national dairy product brands, providing more and more consumers with access to quality dairy products.

Additional factors may lead to the continued surge in demand for dairy products in new areas of China. The school milk program is being promoted in an increasingly wider set of regions each year. The commercialization of the media, the expansion of cable television and television ownership in small towns and rural areas is increasing rapidly. In many of China's small cities, towns, and wealthier rural areas, consumers are beginning to hear the same messages about the benefits of regular milk consumption. More and more households are purchasing larger and better refrigerators, so they will have the ability to store milk and yogurt properly.

Finally, the rise of rural to urban migration will put upward pressure on the demand for all livestock commodities, including dairy. Although one of the greatest factors limiting growth of dairy product demand in China in the future will be income levels, as rural households begin to move into urban areas, demand will summarily rise. Even when income level is held constant, Huang and Bouis (2001) and Huang and Rozelle (1996) have shown that the newly arriving migrants begin to shift toward the consumption patterns of their many urban counterparts. Hence, in addition to the effects created by increased income, the fact that migrants are working and living in an urban environment changes the way they consume.

Recent projections of China's dairy product consumption reported by Dong (forthcoming) are generally consistent with the previous assertions regarding the future growth of dairy demand. Assuming 7.0 percent annual growth in real per capita expenditures in urban China, Dong projects average urban fluid milk consumption will reach 32.04 kg per person in 2014, an annual rise of 5.1 percent. Over the same period, average fluid milk consumption in rural households is projected to reach just 1.5 kg per person. Total dairy product demand in China is anticipated to grow by 50 percent in milk equivalent terms. As China's consumption has expanded over the last two decades, domestic production has very nearly kept pace (Table 4). Meeting the additional demand projected by Dong with domestic milk would require production in China to increase 11.2 million metric tons over the 2003 level. In the next section, we seek to understand the dynamics of how producers have been able to satisfy rising consumption in the past and how well China's dairy sector is positioned to meet the expected demand in the coming years.

Producing Dairy Products in China

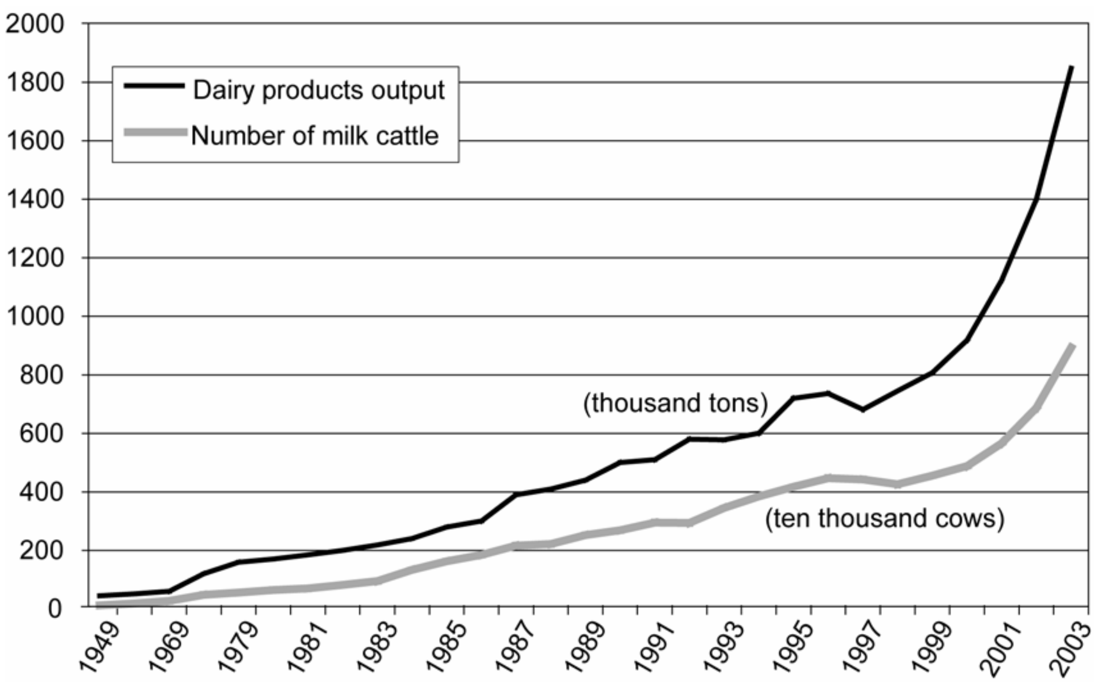
China's dairy production was only about 1 million tons per year in 1980 (Table 4). During the following 15 years, output increased steadily, by about 14 percent annually. However, because China was starting from such a low base, total dairy production was only 6 to 7 million tons by the mid-1990s, a level that placed China about 20th in overall

TABLE 4. The production of dairy products and cattle inventories in China, 1949-2003

Year	Annual per Capita Consumption	Dairy Production	Milk Production	Milk Cattle	Water Buffalo	Beef Cattle
	(kg)		million tons		million head	
1949		0.2	0.2	0.12	10.18	28.67
1959	1.8	0.4	0.3	0.19	12.91	43.06
1969		0.6	0.5	0.27	15.45	43.55
1978	1.02	1	0.9	0.48	17.72	43.55
1979		1.3	1.1	0.56	18.38	42.96
1980		1.3	1.1	0.64	18.52	42.78
1981	1.39	1.5	1.3	0.7	18.77	43.48
1982		2	1.6	0.82	19.14	45.51
1983		2.2	1.8	0.95	19.15	46.98
1984		2.6	2.2	1.34	19.51	49.39
1985	2.77	2.9	2.5	1.63	19.93	52.66
1986	3.15	3.3	2.9	1.85	20.43	56.58
1987	3.53	3.8	3.3	2.16	20.89	58.59
1988	3.84	4.2	3.7	2.22	21.07	60.66
1989	3.87	4.4	3.8	2.53	21.4	76.83
1990	4.16	4.8	4.2	2.69	21.69	78.5
1991	4.53	5.2	4.6	2.95	22.01	79.64
1992	4.81	5.6	5	2.94	22.2	82.5
1993	4.75	5.6	5	3.45	22.55	86.69
1994	5.19	6.1	5.3	3.84	22.91	92.4
1995	5.68	6.7	5.8	4.17	23.58	99.3
1996	6.16	7.4	6.3	4.47	21.72	80.77
1997	6.35	6.8	6	4.42	22.23	86.82
1998	6.07	7.4	6.6	4.27	22.67	93.32
1999	6.7	8.1	7.2	4.56	22.59	94.37
2000	7.64	8.8	7.8	4.88	22.82	96.57
2001	8.79	11.2	10.3	5.66	22.68	95.3
2002	7.78	14	13	6.87	22.72	96.45
2003	9.82	18.5	17.5	8.93	22.28	99.55

Data sources: Before 2003: Wang 2002. For 2003 and 2004: CNBS *China Statistical Yearbook* 2003, 2004.

milk production internationally. Since the mid-1990s, there has been a clear structural break in dairy production (Figure 1, Table 4). Between 1997 and 2003, the growth of dairy production accelerated to nearly 20 percent annually. Aggregate production rose to more than 18 million tons in 2003, a level that ranks China seventh in the world in cow milk production and eighth in total milk production. Unlike some other Asian countries, almost all of China's milk production was generated by milk cows during this period.



Data sources: Before 2003: Wang 2002. For 2003 and 2004: CNSB *China Statistical Yearbook* 2003, 2004.

FIGURE 1. The growth of China's milk sector, 1949-2003

Expanding Production, Expanding Herd Size

Milk production is implicitly the product of the number of dairy cows and the productivity per cow, so growth in milk production is the result of changes in these two components. By far the most prominent source of growth of milk production in China has been the expansion in the dairy herd (Table 4, Figure 1). In 1980, there were only about 640,000 dairy cows in China. Between 1980 and 2000, China's dairy cow herd grew at a rate of about 11 percent annually, just under that of aggregate dairy and milk production. By 2000 there were 4.88 million dairy cows in China. Although delayed by two to three years, China's dairy cow herd size rose by 20 percent annually after 2000, matching the growth of milk production. By 2004, there were 8.93 million dairy cows in China. The rate of growth for the dairy herd is even more remarkable when compared with the meager rise in water buffalo (less than 1 percent growth annually) or the beef cattle inventories (about 3.5 percent growth annually).

Productivity Gains: Technology and/or Efficiencies or Not?

Productivity per cow is the second component of milk production. It is important to understand how changes in the productivity of the sector have contributed to the growth in output. The analysis and data required to study the productivity of China's dairy sector, however, is not trivial, and relying on standard indicators can create an ambiguous picture. The sector is dynamic and constantly changing at both the producer and processing levels. Milk production technology is extremely heterogeneous, ranging from farmers in remote, mountainous villages with one or two dairy cows to state-of-the-art dairy operations with hundreds of cows. New technologies and high-quality genetics are increasingly available but it is unclear to what extent China's small farmers have been able and willing to use them. Complicating matters further, China's National Statistical Bureau does not collect information on many of the key statistics that are critical to understanding some of the most fundamental elements of the sector.

Using information sources that we have been able to gain access to, partial productivity and cost data also lead to unclear results.[3] Milk output per cow in both the specialized household and commercial/collective/state-owned farm sectors have risen (Table 5, column 1). Although somewhat low by international standards, milk yields for specialized dairy households rose steadily during the 1990s and are substantially above the national average of roughly 2,600 kg per cow. Output per man-day also has risen (column 2), partly because of rising yields and partly because of a reduction in annual man-days used per cow. At the same time, the total cost per ton of milk has risen (column 3). Hence, until a multivariate analysis is performed, it is unclear whether or not productivity has increased. Moreover, even if we could ascertain that productivity growth has occurred, it is important to understanding whether or not the growth was generated by adoption of new technologies or by increased efficiency in the use of current technologies. The answer to that question has bearing on expectations of potential for future growth.

Potential for Gains from Technical Change

There is little doubt that China's dairy technology has improved since the pre-reform era. Before 1980 there were almost no genetically improved dairy cows, and most of the dairy cows were owned and managed by state farms and collectives that used extremely

TABLE 5. Milk yield, output per man-day of labor and production costs in China, 1992-2003.

Year	Yield (kg/cow)	Milk Output of Per Labor Man-Day (kg)	Cost (yuan/ton)
	(1)	(2)	(3)
		Specialized Household Dairy Farms	
1992	4335	42.2	680
1993	4234	32.4	837
1994	5159	48.5	924
1995	4998	41.1	1236
1996	4705	64.9	1292
1997	5071	60.4	1559
1998	4602	65.7	1304
1999	4421	67.1	1261
2000	5032	64.4	1186
2001	5121	78.4	1244
2002	5226	68.4	1349
2003	5342	88.4	1329
1992-97	4750	48.3	1103
1998-03	4957	72.1	1280
		State and Collective Dairy Farms	
1992	4744	35.9	844
1993	4736	49.0	983
1994	4477	47.8	1348
1995	4757	60.9	1726
1996	5139	55.1	1917
1997	5155	63.8	1816
1998	5435	86.9	1718
1999	5889	89.9	1619
2000	6019	92.9	1674
2001	6000	93.5	1671
2002	6032	93.7	1665
2003	6091	97.6	1774
1992-97	4835	52.1	1452
1998-03	5911	92.4	1687

Data source: National Agricultural Production Cost and Return Survey.
Note: Total revenue is equal to total milk output multiplying farmgate sale price. All value terms are calculated at present price.

labor-intensive methods and poor-quality rations. Feed mixes rarely included any concentrates, vitamins, or other supplements.

Since 1980, improved genetic material, feeding regimes, and milking and handling equipment have become available, partly as a result of several large and sustained government-to-government development aid efforts undertaken by the European Union, Canada, the World Bank, and other international agencies. More recently, China's government has relaxed restrictions on the import of dairy technology, and greater numbers of private and quasi-private enterprises are introducing new genetics and feeding technologies (CCICED 2004). For example, between 1995 and 2000, China imported a total of 3,200 breeding cows and 300 kilograms of bull semen. In the years 2001 and 2002, imports jumped to 14,000 breeding cows, and bull semen imports rose to 500 kilograms (CNBS 2003). With such a dramatic rise in imports of improved technical inputs, it is conceivable that productivity should increase sharply because of technological change.

However, there are many reasons to believe that technology might have difficulty spreading throughout the dairy sector despite its growing availability. In an industry that is characterized by hundreds of thousands of small producers, there are many possible barriers to the adoption of new technologies. For example, credit constraints arising from a banking system that is unfriendly to producers could prevent farmers from investing in new technologies (Findlay et al. 2003). The lack of a strong extension system hinders the spread of new technologies, especially among a poorly educated farm population (CCICED 2004). In many nations, production and marketing cooperatives provide support to small farmers for technology adoption. Although China's new leadership is promoting farmer professional associations (FPAs), through 2003, less than 7 percent of villages and only 2 percent of farmers belonged to FPAs (Shen et al. 2005).

Changes in Efficiency

Possession of advanced technology does not imply efficient production. Efficiencies can be achieved through specialization along lines of comparative advantage or through exploitation of scale economies. However, these gains can be offset by market and information inefficiencies associated with a swiftly changing market environment and institutions that struggle to adjust. There is anecdotal evidence that China's dairy sector may be experiencing both efficiency gains and losses, but the net effect is an empirical question.

Specialization and Concentration of Dairy Production. The rise of milk production from 1996 to 2003 has not occurred evenly across China (Table 6). In fact, the data show a tendency for production to specialize in two dimensions. First, the bulk of the rise in milk production during this period took place in North China (including all provinces that

TABLE 6. Number of milk cows by province in China, 1996 and 2003

Province	1996	2003	Increase between 1996 to 2003
		1,000 head	
Beijing	57	181	124
Tianjin	29	133	105
Hebei	483	1,304	821
Shanxi	114	214	100
Inner Mongolia	804	1,445	641
Liaoning	72	146	74
Jilin	102	117	18
Heilongjiang	973	1,176	203
Shanghai	60	61	1
Jiangsu	34	142	108
Zhejiang	29	77	49
Anhui	11	41	30
Fujian	23	69	47
Jiangxi	24	36	12
Shandong	94	554	460
Henan	26	165	139
Hubei	41	57	16
Hunan	71	25	-46
Guangdong	25	41	16
Guangxi	6	24	19
Chongqing	0	26	26
Sichuan	43	152	109
Guizhou	16	27	11
Yunnan	78	151	73
Tibet	0	40	40
Shaanxi	96	329	233
Gansu	229	193	-36
Qinghai	81	154	73
Ningxia	71	130	59
Xinjiang	783	1,724	941
Total	4,470	8,932	4,462

Data sources: For 1996: Wang 2002. For 2003: CNBS *China Statistical Yearbook* 2003, 2004.

are north of the Yangtze River). Only 4 percent of the growth in dairy cow inventories occurred in South China. Hunan province in South China actually experienced a decline in dairy cow numbers.

Second, within north China, there has been substantial geographic concentration of dairy cows at the provincial level (Table 6). The largest increase in dairy cow numbers occurred in Xinjiang, with almost one million cows added in just this one province. In addition, a dairy belt is developing that runs from Heilongjiang and eastern Inner Mongolia in the north to Hebei and Shandong on the North China Plain. Xinjiang and the four emerging dairy belt provinces fully account for 70 percent of the rise in China's dairy herd. This increasing geographic specialization of dairy production is consistent with the results of a recent survey by the Center for Chinese Agricultural Policy in China that shows there is increasing specialization in all agricultural sub-sectors—field crops (especially vegetables), tree crops, and livestock—as the nation's commodity markets improve (Huang, Rozelle, and Bi 2005).

Scale Effects. In the United States and other mature dairy markets around the globe, there are fairly strong economies of scale associated with dairy production. As the size of a dairy herd rises, the average cost per ton of milk produced falls because fixed costs can be spread over more milk units. Even through the mid-1990s the scale of the average Chinese dairy producer was extremely small. According to the 1997 census of agriculture, more than three-quarters of the dairy herd was owned by individual farmers; the average dairy farmer in 1996 owned only three cows (Zhou, Tian, and Zhou 2002). There was a newly emerging commercial dairy sector, but in many cases the firms were state or collective owned.

Given the lack of systematic data, it is difficult to gauge what has happened to the average herd size for dairy since the mid-1990s. Drawing on the experience of the swine sector, we might conclude that there has been little change. Chen (2002) shows that after the commercial swine sector expanded in the early 1990s, there was a resurgence of backyard hog production due to improvements in transportation that allowed feed and feed supplements to more easily move into and live hogs to move out of poorer inland areas where the opportunity cost of labor was lower. During the same period, the commercial hog sector was nearly stagnant. In a survey conducted in 2000 by the Center for

Chinese Agricultural Policy in Beijing, sample households raising dairy cows owned an average of four cows, a level that was statistically indistinguishable from the three cows per household found in the 1997 census. Finally, during our interviews over the past several years, we have discovered that there are many regionally supported dairy programs. In many cases, the main policy tool is a small bank loan package designed to help farmers who are new to the dairy industry. Typically, the loans are big enough to purchase one to three dairy cows.

While on the surface it does not appear that economies of scale are being exploited at the household level, the bulky and very perishable nature of milk implies that the dairy sector may evolve differently from the swine sector. There are strong incentives for processing firms to promote larger-scale dairies in order to make effective use of technologies that increase the quality of the milk and reduce the transaction costs of milk collection. Indeed, there is some evidence that the commercial sector may be making some inroads and that there may be a healthy "specialized household" sector that is increasing its share of the national herd (e.g., World Bank 2005; Wang 2002).

More importantly, dairy processors are playing a strategic role in capturing scale economies through collective action. In some places, unique institutional structures have appeared to try to capture scale effects. For example, in Inner Mongolia we observed several processor-run milking stations where farmers can bring their cows and milk them using the processor's milking machine. The milk goes directly into the processor's bulk cooling tank, and farmers receive the market price for the milk. In Yunnan and Sichuan, farmers can buy or rent stalls in a commercial milking shed where they can house and milk their cows. The farmer is responsible for feeding and providing care for the cow, while the milking shed manager keeps the milking and cooling equipment operating and coordinates deliveries to and payments from the processors. Unfortunately, with the lack of comprehensive statistics, it is unclear how common such arrangements are; nevertheless, the fact that such operations are created demonstrates the importance that processors place on increasing the scale and sophistication of milk production.

Disequilibria from Expansion and Institutional Change. Even if one could unambiguously conclude that the trends in concentration and scale expansion are leading to efficiency gains, it is certainly possible that in net aggregate terms the torrid pace of development in the dairy industry is creating so much change and disequilibria that measured efficiency (at least temporarily) is falling. It is difficult to depict a "typical" dairy producer, processor, or retailer because all parts of the industry are changing so fast. When the herd size is growing by 20 percent per year, this means that every four years (e.g., between 2001 and 2004) the number of cows in China doubles. New producers are entering. Experienced producers are changing their genetics and upgrading their milking facilities. Commercial operations are weighing options and changing management incentive plans and control rights regimes, and they are altering the way they interact with small producers, processors, and local governments. Indeed, it is well recognized in the economics literature that there are often high adjustment costs that can lead to inefficiencies as industries and firms in industries make new investments and change their technologies (e.g., Lucas 1967; Johnson and Quance 1972).

Visits to production areas reveal that there may be inefficiencies related to the growing pains of the industry, especially in the ways that processors are interacting with producers during periods of supply expansion in a locality. According to one major Shanghai dairy processor, more processing plant capacity has been built in China during the past five years than during the entire history of milk production in China. However, the stories recounted by producers, agents of processors, and local government officials make it clear that establishing raw milk supplies for a new processing plant entails more than simply introducing a new set of farmers to the milk market in some orderly fashion. On the contrary, in many places the construction of a new processing plant sparks a series of local dairy wars. Before a plant can be successfully established, it must create reliable links with producers and have a set of implicit production, collection, and pricing rules. Establishing a full set of suppliers takes both time and financial resources. However, as soon as a new plant comes on line there is immediate pressure to use as much of the capacity as possible to reduce the capital costs per ton of production. In most cases, the new plants are unwilling to invest the time and effort into the development of their own set of suppliers from scratch. Instead, they often opt, at least in part, to induce producers in the area to switch from their current buyer to the new processing firm. Even when milk producers are bound by a written contract to supply a particular processor (which is rare), there are few legal remedies to prevent one firm from poaching producers from another firm's raw milk supply base. We have encountered producers who have switched suppliers every several months for a period of years. Of course, once new supplies are drawn into the market, an oversupply can occur, and individual producers are sometimes informed that they will no longer be serviced (again, whether or not they have a written contract or oral agreement with a processing firm). All of these instances can of course cause confusion and uncertainty and most can lead to a decline in the industry's efficiency, at least temporarily.

An Empirical Analysis of Productivity, Technical Change, and Efficiency Shifts

It is clear from the previous discussion that a large share of the rise of China's dairy production can be attributed to the increase in the dairy herd; however, empirical evidence is lacking concerning the direction, magnitude, and source of any changes in productivity. In this section, we address this deficiency by estimating a stochastic production frontier for China's dairy sector. We decompose the estimated productivity growth into components resulting from technical change and from shifts in productive efficiency. In the discussion that follows, we briefly present the empirical model, data, and key results.

Methodology

Traditional studies of productivity growth in agriculture have tended to compute productivity as a residual after accounting for input growth, and to interpret the growth in productivity as the contribution of technical progress. Such an interpretation implies that improvements in productivity can arise only from technical progress. However, this assumption is valid only if firms are technically efficient, thus operating on their production frontiers and realizing the full potential of the technology. The fact is that for various reasons firms do not operate on their frontiers but somewhere below them, and total factor productivity (TFP) measured in this way can reflect both technological innovation and changes in efficiency. Therefore technical progress may not be the only source of total productivity growth, and it will be possible to increase factor productivity by improving the method of application of the given technology—that is, by improving technical efficiency.

To study production efficiency, the stochastic frontier production function (Aigner, Lovell and Schmidt 1977) has been the subject of considerable recent research with regard to both extensions and applications (Battese and Coelli 1995). Stochastic production function analysis postulates the existence of technical inefficiency of production of firms involved in producing a particular output, which reflects the fact that many firms do not operate on their frontiers but somewhere below them. Many theoretical and empirical studies on production efficiency/inefficiency have used stochastic frontier production analysis (e.g., Coelli, Rao, and Battese 1998 and Kumbhakar and Lovell 2000).

As panel data permit a richer specification of technical change and obviously contain more information about a particular firm than does a cross-section of the data, recent development of techniques for measuring productive efficiency over time has focused on the use of panel data (Kumbhakar, Heshmati, and Hjalmarsson 1999 and Henderson 2003). Panel data also allow the relaxation of some of the strong assumptions that are related to efficiency measurement in the cross-sectional framework. In the rest of the paper, we adopt a panel data approach to measure and decompose TFP for China's dairy sector.[4]

As in Kumbhakar (2000), the stochastic frontier production function for panel data can be expressed as

$$y_{it} = f(x_{it}, t)\exp(v_{it} - u_{it}) \tag{1}$$

where y_{it} is the output of the *i*th firm $(i = 1, 2, \cdots, N)$ in period t $(t = 1, 2, \cdots, T)$; $f(\cdot)$ is the production technology; x is a vector of J inputs; t is the time trend variable; v_{it} is assumed to be an iid $N(0, \sigma_v^2)$ random variable, independently distributed of the u_{it}; and u_{it} is a non-negative random variable and output-oriented technical inefficiency term. There are several specifications that make the technical inefficiency term u_{it} time varying, but most of them have not explicitly formulated a model for these technical inefficiency effects in terms of appropriate explanatory variables.[5] Battese and Coelli (1995) proposed a specification for the technical inefficiency effect in the stochastic frontier production function as

$$u_{it} = z_{it}\delta + w_{it} \tag{2}$$

where the random variable w_{it} is defined by the truncation of the normal distribution with zero mean and variance σ^2, such that the point of truncation is $-z_{it}\delta$, i.e., $w_{it} \geq -z_{it}\delta$. As a result, u_{it} is obtained by truncation at zero of the normal distribution with mean $z_{it}\delta$

and variance σ^2. The normal assumption that the $u_{it}s$ and $v_{it}s$ are independently distributed for all $i = 1, 2, \cdots, N$ and $t = 1, 2, \cdots, T$ is obviously a simplifying but restrictive condition.

Technical inefficiency, u_{it}, measures the proportion by which actual output, y_{it}, falls short of maximum possible output or frontier output, $f(x,t)$. Therefore technical efficiency (TE) can be defined by

$$TE_{it} = y_{it} / f(x_{it}, t) = \exp(-u_{it}) \leq 1. \tag{3}$$

Time is included as a regressor in the frontier production function and used to capture trends in productivity change—popularly known as exogenous technical change—and is measured by the log derivative of the stochastic frontier production function with respect to time (Kumbhakar 2000). That is, technical change (TC) is defined as

$$TC_{it} = \frac{\partial \ln f(x_{it}, t)}{\partial t}. \tag{4}$$

Productivity change can be measured by the change in TFP and is defined as

$$\dot{TFP}_{it} = \dot{y}_{it} - \sum_J S_{jit} \dot{x}_{jit} \tag{5}$$

where S_{jit} is the cost-share of the *j*th input for the *i*th firm at time *t*. Kumbhakar has shown that the overall productivity change can be decomposed by differentiating equation (1) totally and using the definition of TFP change in equation (5). This results in a decomposition of the TFP change into four components: a scale effect, pure technical change, technical efficiency change, and the input price allocative effect.

Data

An ongoing problem for the study of livestock productivity in China is obtaining relevant and accurate data. The majority of published studies of Chinese agricultural productivity have used data published in China's Statistical Yearbook. While this source disaggregates gross value of agricultural output into crops, animal husbandry, forestry, fishing, and sideline activities, input use is not disaggregated by sector. A major improvement we introduce is to utilize additional data collected at the farm level that will allow the construction of time-series of input use by the livestock farm type.[6] These data have been used and published for studies on livestock output trends and productivity (e.g., Ma et al. 2004; Jin et al. 2002).

There are several problems with using cow numbers that are needed to estimate changes in livestock productivity over time. Livestock data from the official statistical yearbooks is the apparent over-reporting of both livestock product output and livestock numbers (Fuller, Hayes, and Smith 2000). Although this problem also needs to be addressed if the possibility of biased productivity estimates is to be avoided for most livestock products, because there are milk production statistics available for reconciliation with dairy cow numbers, it is less likely dairy statistics are subject to the same degree of over-reporting. We do, however, address this issue. Specifically, Ma, Huang, and Rozelle (2005) use the 1997 national census of agriculture as a baseline to provide an accurate estimate of the size of China's livestock economy in at least one time period. The census is assumed to provide the most accurate measure of the livestock economy since it covers all rural households and non-household agricultural enterprises. The census also collected information on the number of animals in inventory at the end of the 1996 calendar year. A second source of additional information is the official annual rural household income and expenditure survey (HIES) that is run by the China National Bureau of Statistics (CNBS). Information collected in that survey includes the number of livestock slaughtered and the quantity of milk. Ma, Huang, and Rozelle assume the production data as published in the *China Statistical Yearbook* to be accurate only through the end of the 1980s. Beyond this date, data are adjusted both to reflect the annual variation as found in the HIES data and to agree with the census data for 1996. Further details of the adjustment procedure can be found in Ma, Huang, and Rozelle 2005. The adjusted series includes provincial data on livestock production, animal inventories, and slaughters. Since dairy cattle are not included in that study, we use a similar approach to adjust data on milk output and dairy cattle inventories.

Feed, Labor, and Non-livestock Capital Inputs

Provincial data for the production inputs are obtained directly from the Agricultural Commodity Cost and Return Survey.[7] Thought to be the most comprehensive source of information for agricultural production in China, the data have been used in many other studies (e.g., Huang and Rozelle 1996; Jin et al. 2002). Within each province a three-stage random sampling procedure is used to select sample counties, villages, and finally individual production units. Samples are stratified by income levels at each stage. The cost and return data collected from individual farms (including traditional backyard households, specialized households, state- and collective-owned farms, and other larger commercial operations) are aggregated to the provincial and national level data sets that are published by the State Development Planning Commission.

The survey provides detailed cost items for all major animal commodities, including those covered in this paper. These data included labor inputs (days), feed consumption (grain equivalent), and fixed asset depreciation on a "per animal unit" basis. We deflate the depreciation data using a fixed asset price index. We calculate total feed, labor, and non-livestock capital inputs by multiplying the input per animal by number of animals. For the latter, we use the opening inventories for milking cows since these are the "animal units" used in the cost survey. It is clear that this procedure, necessitated by the available data, excludes some input usage, but this is probably unavoidable and as long it is consistent over time the amount of bias should not be too serious.

Livestock Production Structures

As previously discussed, China's dairy sector is experiencing a rapid evolution in production structure, with potentially large performance differences across farm types. For example, specialized household producers utilize more readily available feedstuffs, while commercial/collective/state-owned enterprises feed more grain and protein meal. If there is a trend from specialized household and commercial enterprises in livestock production systems (which may be occurring), it could imply an increasing demand for grain feed (Fuller, Tuan, and Wailes 2002). We follow an approach similar to that used by Ma et al. (2004) to adjust for changing production structures.[8]

Sample Size

Our panel data are unbalanced since for any livestock and farm type not all years may be present nor may all provinces be present for any year. Data on milk production covers the 1992-2001 period. The number of provinces for which complete data sets are obtained also varies across years and farm types (Table 4).

Estimation and Results

We define the stochastic frontier production function in translog form:

$$\ln y_{it} = \alpha_0 + \sum_j \beta_j \ln x_{jit} + \beta_t t + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} + \frac{1}{2}\beta_{tt} t^2 + \sum_j \beta_{jt} \ln x_{jit} t - u_{it} + v_{it} \qquad (6)$$

where *ln* denotes the natural logarithm, $i = 1, 2, \cdots, N$ indexes the provinces, $t = 1, 2, \cdots, T$ indexes the annual observations over time; y_{it} is total output as defined previously; j indicates inputs and *t* is a time trend. The technical inefficiency function u_{it} is defined as

$$u_{it} = \delta_0 + \delta_1 t + \sum \delta_{2i} D_i \qquad (7)$$

where D are provincial dummies.

Since there are serious econometric problems with two-stage formulation estimation (Kumbhakar and Lovell 2000, p. 264), our study simultaneously estimates the parameters of the stochastic frontier function (6) and the model for the technical inefficiency effects (7). The likelihood function of the model is presented in the appendix of Battese and Coelli (1995). The likelihood function is expressed in terms of the variance parameters $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma \equiv \sigma_u^2 / \sigma^2$, and γ is an unknown parameter to be estimated. The stochastic frontier function may not be significantly different from the deterministic model if γ is close to 1 (Coelli, Rao, and Battese 1998, p. 215). On the other hand, if the null hypothesis $\gamma = 0$ is accepted, this would indicate that σ_u^2 is zero and thus the term u_{it} should be removed from the model, leaving a specification with parameters that can be consistently estimated by ordinary least squares. We use the Frontier 4.1 computer program developed by Coelli (1997) to estimate the stochastic frontier function and technical inefficiency models simultaneously and this program also permits the use of our unbalanced panel data.

To test the appropriateness of our model specification, we conducted various hypothesis tests before the final stochastic frontier function was chosen. The hypothesis tests show that in each case the translog stochastic frontier production function was an appropriate functional form and that livestock production demonstrates significant technological change and factor input biases.

Because of the unbalanced nature of our panel data, some explanation about the procedures used in constructing tables of results is required. First, while average productivity growth rates are presented for the entire 1991-2001 period, there are insufficient degrees of freedom to allow us to present results for the early 1990s and the 2000-2001 period. Second, individual provincial results are included in growth rate calculations, provided that at least six provincial observations are available within the relevant time period. Third, provincial results are averaged to the regional level using output shares as weights. Finally, overall average productivity results are obtained by averaging the regional results, again using output shares as weights.[9]

According to our results, annual growth in milk production over the 1990s on specialized and commercial farms was around 9 percent and 5 percent per year (Table 7, columns 1 and 5). Hence, compared with the overall production rates of growth for the entire 1990 to 2001 period (Table 4), the reported rates are somewhat lower. In part, this is due to the adjustments made to output during the data preparation phase of the analysis. It is also possible that this result indicates that small-scale producers have contributed more to output growth than have specialized households and commercial operators.

Significantly, although output growth is robust, only a small part of it is due to a rise in TFP (Table 7, columns 2 and 6). Only 0.48 percent of growth in the specialized household sector and 1.31 percent of growth in the commercial sector is from rising TFP. Hence, according to our results, the growth of inputs, heifer purchases, feed concentrate expenditures, equipment and other inputs account for much of the output growth. In other work, Rae et al. (2004) conduct similar analyses for hog production, poultry, and other livestock commodities. Compared with almost all other livestock sectors (with the

TABLE 7. Annual growth (%) in milk total factor productivity (TFP) and decomposition into technical efficiency (TE) and technical change (TC), 1990s

	Specialized Households				Commercial Operations			
Region [a]	Output	TFP	TE	TC	Output	TFP	TE	TC
North	4.75	2.87	-5.25	8.13	2.84	-0.60	-5.60	5.01
Central	14.82	0.02	-7.31	7.33	12.18	-0.87	-6.99	6.12
South	-4.55	8.93	-7.99	16.92	-1.99	6.37	-0.58	6.96
Southwest	–[b]	–	–	–	-2.73	9.05	-8.83	17.88
West	11.48	-2.50	-6.45	3.95	10.47	1.15	-0.35	1.50
Mean	8.81	0.48	-6.09	6.58	5.25	1.31	-3.26	4.57

[a] For specialized households: North: Tianjin, Mongolia, Liaoning, Jilin and Heilongjiang; Central: Hebei, Shandong and Henan; South: Anhui and Fujian; West: Shaanxi and Xinjiang. For commercial operations: North: Beijing, Tianjin, Mongolia, Liaoning and Jilin; Central: Hebei, Shandong, Henan and Hubei; South: Shanghai, Jiangsu, Anhui, Fujian, Hunan, Guangdong; Southwest: Guangxi and Chongqing; West: Shaanxi, Gansu and Xinjiang. In total, these provinces accounted for 59% and 57% of specialized household and commercial farm output in 1999-2001.

[b] Data unavailable.

exception of backyard hog production), the share of output growth contributed by TFP is the lowest for milk production by far. In other words, in recent years the rise of TFP has played an important role in the expansion of most other livestock sectors, but not in the dairy sector.

Although TFP growth has been relatively slow, the contribution of technology (or TC) has played an important role (Table 7 columns 4 and 8). Overall, TC generated a 6.58 percent annual increase in productivity in the specialized household sector and a 4.57 percent increase in the commercial sector. Indeed, most of the productivity growth in the specialized and commercial dairy sectors, according to these results, has been due to the adoption of improved genetics, milking processes, and other management methods. Following this logic, the bulk of the dairy cows added to the herd in recent years has been in the backyard household sector. Interestingly, while TFP growth for dairy was low compared to the rest of the livestock sectors, the contribution of technology is among the highest.

If TFP growth it modest and TC is high, it must mean that there has been a summary decline in efficiency of the sector during the 1990 to 2001 study period. Columns 3 and 7 in Table 7 show that, had it not been for the decline in efficiency, output growth would have risen by 6.09 percent more in the specialized household sector and 3.26 percent in the commercial sector. Although it is hard to determine the exact source of the reduction in efficiency, our analysis allows us to surmise that it is not due to a fall in scale economies. There were very small gains in scale economies (results not shown). The rising concentration in the industry suggests that a lack of specialization at the regional level is not the cause, although there is no data indicating whether or not specialization at the community level has risen or fallen. Assuming it has not declined, the main cause of the fall in efficiency may be some sort of disequilibria effect arising from the very high rates of growth during the study period. If this is actually the real reason for the drop in efficiency, the future prospects for production may be fairly bright, assuming growth of the industry moderates and processors begin to rationalize their supply bases.

Our results also show some of the dynamics of regional production (Table 7, rows 1 to 5). Against the trend, the specialized households in the South (which is dominated by Shanghai, Jiangsu, and Anhui) experienced a growth in TFP of nearly 9 percent. Rising technical change contributed nearly 17 percent. There also was fairly high growth due to technology in the specialized household sector in North (8.13 percent) and Central China (7.33 percent). While positive in the West, the rate of technological change (3.95 percent) was not great enough to offset the rise in inefficiency. The highest rate of technological change in the commercial sector was in the Southwest region (17.88 percent).

Looking Ahead

The story of China's dairy industry over the past decade has been a simple one: Demand has risen rapidly. In addition to greater purchasing power, shifting preferences prompted by a new awareness of the health benefits of milk have greatly increased demand. Indeed, in recent years milk is being consumed by a broad cross section of China's population. Where did most of the supply come from to meet the new demand? By far the greatest proportion has come from China's emerging domestic dairy industry. Driven primarily by increases in the dairy herd and adoption of new technologies, domestic supply has risen as fast as demand. There is evidence that considerable inefficiencies remain in the dairy sector, and there is great potential for future improvements in productivity per cow. Consequently, there is good reason to believe that production can continue to rise in the future, given the appropriate market environment.

Looking ahead, there are many reasons to believe the rapid growth in demand for dairy products will continue unabated in China. Incomes are forecast to continue to rise. If China is successful in modernizing, there will be hundreds of millions of new urban residents. As the dairy processing industry matures and becomes even more competent, it is likely the media attention, advertising, and promotion of dairy products will accelerate. All of these factors will contribute to a growing number of households that integrate dairy products into their daily diets. Most importantly, as today's generation grows up in an environment that increasingly accepts dairy consumption, these attitudes become entrenched and are passed from parent to child. It is likely that the growth in dairy demand observed in the last decade is just the start of a long, sustained expansion of China's dairy consumption.

How will China's dairy industry continue to satisfy growing demand in the future? Certainly, China's dairy herd will expand. However, if the domestic dairy industry is to be successful at keeping pace with rising consumption, it will have to continue to adopt new technologies and increase efficiency. There is tremendous scope for increasing economies of scale in milk production in China, both at the firm level and collectively, and it is incumbent on the dairy industry to find innovative ways to work with rural households to increase production scale. Likewise, productivity per cow must rise. Currently, milk production per cow is less than half the international average. Although it will not happen immediately, as the dairy industry is successful in adopting better genetics, better management practices, and improved feeding regimes, milk production can double at the current herd size. Of course, expanding cow numbers and raising productivity likely will require large increases in grain and protein feed consumption. Finally, institutions within the industry or within the government need to develop constructive methods for coordinating expansion of raw milk production and processing. The inefficiencies and confusion induced by struggles over milk supplies are symptoms of larger problems associated with inadequacies in contract law and enforcement, agricultural lending and capital markets, and market information channels.

Clearly China's dairy industry will face many challenges in the coming years. In addition to finding adequate raw milk supplies, the processors will face growing competition in product markets. As China's consumers become wealthier, they will demand safer and higher quality products. Competition between regional dairy companies within China has been growing, and the dairy processing sector in China will continue to consolidate and rationalize productive capacity as a truly national dairy market emerges. Multinational firms have already entered dairy markets in China, and with the relaxation of import barriers and constraints on foreign investment under China's World Trade Organization commitments, competition from abroad will only increase.

Before entry into the World Trade Organization, China's average tariff for dairy products was more than 50 percent. By 2004, the average tariff fell to only 11 percent, and there are no tariff rate quotas. In response, trade has risen for traditional products, such as milk powder, and also for processed goods. It is likely that China's imports of cheese and other high-valued processed dairy products will continue to grow in the coming years, in part because there is little domestic production of these goods. Import trends for milk powders and butterfat are less predicable because they depend on the availability of raw milk and the prevalence and cost effectiveness of recombining these protein and fat inputs to create other products. In 2004, a number of large multinational dairy companies increased or made plans to increase their investments in Chinese dairy companies. These investments are likely to facilitate the technology transfer and adoption needed to meet the challenges that lie ahead.

Endnotes

1. Fluid milk equivalent of dairy product consumption reported in the CNBS Urban Household Income and Expenditure Survey. Rural per capita consumption is estimated by subtracting urban consumption from total milk production.

2. Garnaut and Ma were comparing data from Guangzhou to data from Taiwan, Hong Kong, and Singapore when they made their comments about the comparatively low level of milk consumption in Guangzhou. They used Guangzhou data because of its population had greater cultural similarity to the populations in the comparison countries than did the general mainland's population.

3. The cost data are collected by the Price Bureau and the National Economic Development Commission and were provided to the authors for use in this paper.

4. Even though we are only interested in estimating the productivity shifts of a single sector, the dairy sector, we also should make an important methodological decision regarding whether to use a single- or multi-product function. However, in making the decision, this primarily was an issue only for the models of the backyard dairy sector production, since specialized households and commercial operations tend to concentrate on a single livestock type. Since we do not have data on the backyard dairy sector (and only on specialized dairy producers and large commercialized/collective/state-owned dairies), we adopt a single equation estimation approach.

5. See Kumbhakar and Lovell (2000) for a review of recent approaches to the incorporation of exogenous influences on technical inefficiency.

6. Carter, Chen, and Chu (2003), in studying aggregate agricultural TFP growth in Jiangsu province, compared results based on provincial aggregate data with sectorally disaggregated household data. They found that use of the former provided implausibly high TFP growth over the 1988-96 period.

7. This survey is conducted through a joint effort of the State Development Planning Commission, the State Economic and Trade Commission, the Ministry of Agriculture, the State Forestry Administration, the State Light Industry Administration, the State Tobacco Administration and the State Supply and Marketing Incorporation.

8. To estimate productivity growth by farm type, our data must be disaggregated to that level. This is not a problem for the feed, labor and non-livestock capital variables, since they are recorded by production structure in the cost surveys. However, complete data series on livestock output and animal inventories by farm type do not exist. Our approach to generating output data by farm type is to first construct provincial

"share sheets" that contained time-series data on the share of dairy cow inventories by each farm category (specialized and commercial). We note that this assumes a constant inventory share across farm types and therefore assumes away a possible cause of productivity differences in this dimension across farm types. However, it proved impossible to gather further data to address this concern. To disaggregate our adjusted livestock output data by farm type, it is important to take into account yield differences across production structures. From the cost surveys, we obtained provincial time-series data on average production levels per animal (milk per cow). Such information is then combined with the farm-type data on cow inventories to produce total output estimates by farm type that were subject to further adjustment so as to be consistent with the aggregate adjusted output data.

In summary, information that allows us to estimate the inventory and slaughter shares by farm type and by province over time comes from a wide variety of sources. These include the 1997 China Agricultural Census, China's Livestock Statistics, a range of published materials (such as annual reports, authority speeches and specific livestock surveys) from various published sources, and provincial statistical Web sites. The census publications provide an accurate picture of the livestock production structure in 1996 (Somwaru, Zhang, and Tuan 2003). Various years of the *Agricultural Statistical Yearbook* and China's *Livestock Statistics* provide data on livestock production structure during the early 1980s, when backyard production and state farms were prevalent. These sources, plus the the *Animal Husbandry Yearbook* and provincial statistical Web sites also provide estimates of livestock shares for various livestock types, provinces, and years. When all these data are combined with 1996 values from the census, many missing values still existed. On the assumption that declining backyard production and increasing shares of specialized and commercial operations are gradual processes that evolved over the study period, linear interpolations are made to estimate a number of missing values.

The share sheets may be requested from the authors.

9. In the TFP decompositions we do not present the scale effects as they were minor compared with the technical change and efficiency components. We also do not calculate the allocative inefficiency components because of incomplete price data. To save space, we do not report the stochastic frontier production parameter estimates. They are available upon request from the authors.

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