DRAFT – Not to be quoted.

Enhancing Productivity on Dairy Farms in China: Taking the Cows to Town

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Presented to the 50th Annual Conference of the Australian Agricultural and Resource Economics Society, Sydney, 8-10 February 2006.

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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 construction of dairy cattle concentration centres and more cows being driven to the concentration centres, small and scattered dairy farms are gradually disappearing and more concentrated dairy cattle farming is being formed near suburban areas. This paper uses farm 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 technical change and TFP growth have been positive on suburban dairy farms, but that on average such farms have been falling behind the advancing technical frontier. Further, the rate of technical change has been more rapid on suburban farms than for the dairy sector as a whole. The results suggest efforts to achieve a more even adoption of new technologies within the suburban dairy sector will further advance productivity growth in the sector.

Keywords: Distance Function, Productivity Growth, Technical Inefficiency, China, Suburban Dairy Farms.

JEL Classification: D240, Q100, Q160.

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Introduction

Milk production in China is struggling to keep up with demand**.** Dairy products have not been a part of the diet of China's majority Han people over a very long period of time, but increasing affluence and health awareness has encouraged a remarkable shift towards higher quality and healthier food products, including fresh milk and dairy products (Yang, MacAulay and Shen, 2004; Zhou, Tian and Zhou, 2002; Fuller et al., 2004 and 2005). So while milk output has increased from 5.76 million metric tons in 1995 to 17.46 million metric tons in 2003 (CNSB, 1996 and 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. Milk production is the product of cow numbers and yield per cow, and the rapid growth in China's output has thus far been driven primarily by increased animal numbers rather than by higher yields (Yang, MacAulay and Shen 2004). So what have been the trends in dairy farm productivity in China? Has productivity growth been due to technical change, or to more efficient use of existing milk production technologies? The location of milk production in China is moving to suburban areas, closer to the major markets and the urban-based milk processing centres. Rae *et al*. (forthcoming) found that total factor productivity growth in milk production during the 1990s across China averaged only 0.5% and 1.3% per year for specialised households and commercial operations. Since suburban dairy farms tend to be larger, and more intensive and market-oriented than the national average, could it be possible that productivity growth is more rapid on such farms?

In the next section we describe China's dairy farm systems including the suburban milk production sector, followed by a discussion of data and some descriptive statistics for suburban dairy farms. We then use the stochastic distance function methodology to estimate productivity growth in the suburban milk production sector, followed by discussion of our results including a decomposition of productivity into its technical change and efficiency components. The paper concludes with some policy implications of our findings.

Dairy Farm Systems in China

Milk production in China is officially categorised into three systems – pastoral production, cropping area production and suburban systems. The first of these is found mainly in Inner Mongolia, Tibet, Xinjiang, Qinghai and Gansu. A large number of cows are raised in these areas, although they tend to be primarily low quality breeds, and pasture land under this system has suffered severe degradation caused by overstocking. As a result yields in these areas are very low. For example, more than 38% of China's milk cows are raised in Inner Mongolia and Xinjiang, but their output comprised only 24% of the national total in 2003. The relative remoteness of this production system from inland markets means that the market-orientation of production activities is quite limited. Consequently, a large part of output is used for self-consumption and for nursing young animals. Inner Mongolia and Xinjiang, for example, have high shares of national cow milk output (9.5% and 9.0%, respectively), but more that 60% of their milk production was consumed on the farm.[1]

[1] Sales percentages of milk output are calculated based on the China Statistical Yearbook 2000. The rural household production and sale of animal outputs data are originally provided by the Household Income and Expenditure Survey of China. The percentages of sales to total cow milk output for other pastoral areas in 1999 were 0.8% (Tibet), 19.0% (Gansu) and 14.1% (Qinghai).

The cropping area production system is located mainly in Heilongjiang, Liaoning, Hebei, Jiangsu, Shandong, Henan, Sichuan, Yunnan, Shaanxi and Ningxia provinces. This milk production system has become the major production system over the past two decades, encouraged by policy reforms that allow rural households to decide what they can best produce. As a result, a multi-enterprise farming system has become established in which animals are fed with all sorts of edible materials produced on farmers' plots in addition to purchased feed additives. Limited land means that these farmers raise cows in backyard sheds and the scale of milk production is relatively small. Milk is sometimes a by-product of calf production (Zhou, Tian and Zhou, 2002). In most regions this system is primarily market-oriented, with milk consumed locally. This is not always the case though - for example in Sichuan in 1999 more than 80% of milk output was consumed on-farm. With thousands of dairy farms scattered around the countryside, the lack of processing facilities is a constraint to the further development of dairying in these regions. Therefore the cropping area dairy production system is not expected to remain a major commercial producer over the medium term.

The third milk production system is located in suburban areas, including the suburban dairy farms in Beijing, Tianjin, Shanghai, provincial capital cities and other medium-sized cities around China where they have access to industrial processing facilities and major consumer markets. Suburban dairy farms are characterised by their large scale of operation, intensive production and market-orientation, with some developed from state-owned dairy experiment stations. Commercial production and proximity to markets, infrastructure and processing facilities have proved to be essential for quality control (Zhou, Tian and Zhou, 2002).

The size of the suburban dairy farm economy in China can be gauged from various studies and reports. According to MOA (2003), suburban dairy farms milked 62.3% of total cows and produced 54.4% of total milk output in Beijing, Tianjin and Shanghai in 2000, and similar situations also exist in some medium sized cities. Suburban dairy farms in Zigong District produced more than 50% of total milk output in Zigong city in 2003 (ZAB, 2003).[2] Even in Heilongjiang province (which had a 17.2% share of national milk output in 2003), dairy farms are also extremely concentrated. About 90% of the province's dairy cattle are raised in five adjacent areas (Shuangcheng, Zhaodong, Anda, Dumeng and Fuyu according to HLJSB 2002). They are also closely distributed along the railway line from Harbin to Qiqihar with no more than 100km between any two adjacent zones areas (see figure 1).

Several other 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 many medium and large cities and their geographical proximity has in several cases helped overcome the lack of specialised cooling transportation facilities (Zhou, Tian and Zhou, 2002). Second, government has implemented a wide range of measures to promote the development of suburban dairy farms, including the provision of accessional loans for investment, feed subsidies, the supply of improved breeds and the provision of technical assistance to producers. To ensure the local milk supply, many suburban governments have supported dairy farm production and milk processing in their regions, for example through the Food Basket Project and the School Milk Program to encourage healthy diets and food diversity. The injection of

[2] Zigong district belongs to Zigong city that has four separate districts (like Zigong district) and two counties. Zigong city is one of 18 cities and three autonomic prefectures of Sichuan province.

foreign capital and the introduction of advanced technologies is the third factor to have helped promote suburban milk production. Since the mid-1980s, international organisations and foreign governments have provided technical assistance in developing China's suburban dairy farms. For example the UNDP sponsored a project to develop dairy production in six major cities during 1984-90.[3] The EU implemented an even larger project in 20 cities during 1990-94.[4] With a total funding of US$156 million, these projects have made a significant contribution to the increase in suburban milk production (RTDDI, 1997; Tuo, 1999). Large suburban dairy demonstration farms have been successfully constructed in several large northern cities (MSTC, 2004).

Driven by demand-side pressures, intense competition has emerged among processing companies for raw milk (Liao, 2003). This has encouraged the recent phenomenon of dairy cattle 'concentration centres' in suburban areas to ensure the sustainable supply for fresh milk for processing (Miao and Jiang, 2003; MOA, 2003; Yi, 2005a). Small and scattered dairy farmers in the countryside are driving their cows into the concentration centres where they can rent space for their cows, and buy cows to start their business, and enjoy modern production and marketing services such as concentrate feed, new owner training programs, animal disease control, milking facilities, milk collection and transportation (Zhang, 2005). As a result, smaller dairy farms have been gradually disappearing and more and more dairy cattle will be fed in the concentration centres and owned by separate owners (Yi, 2005b). These programmes have promoted intensive dairy farm production and upgraded the

[3] The six cities are Nanjing, Xian, Shanghai, Beiing, Wuhan and Tianjin.
[4] The twenty cities are Shenyang, Dalian, Qingdao, Hefei, Hangzhou, Changsha, Guangzhou, Chengdu, Chongqing, Fujian, Nanchang, Wuxi, Suzhou and Guilin in addition to the previous six cities.

importance of suburban dairy farms in supplying, processing and urban markets with fresh cow milk.[5]

Many dairy cattle concentration centres have already been established by either local governments or dairy companies, and others are planned. For example, nine concentration centres were constructed and 900 households had moved their 15,000 cows, which accounts for about 19% of total inventory, into these centres in Yinchuan of Ningxia Municipality by 2005 (Zhang, 2005). In Harbin of Heilongjiang province, twenty 1000-cattle concentration centres were constructed during 2005 with a further 60 such centres still to be constructed (Xue, 2005). There have been twelve over-1,000-cattle centres (inventory is 28,000 heads) and twenty eight over-300-cattle concentration centres (inventory is 20,000 heads) established in Daqing of Heilongjiang province, housing more than 25% of this region's dairy cattle population of 187,000 cows by the end of 2003 (HAHB, 2003). Nine demonstration concentration centres with 22,000 dairy cattle (accounting for 16% of total inventory) existed in Huhehaote of Inner Mongolia municipality in 2003 (Zhu, Guo and Hu, 2003). In Nanjiao district of Datong in Shanxi province more than 6,500 dairy cattle were fed in concentration centres in 2004, accounting for more than 40% of the total inventory (SIB, 2004). Sanlu Dairy Group invested US$9.2 million in the construction of the Luquan Tongye ecotypic dairy cattle concentration centre of Shijianzhuang in Hebei province, completed by 2003 to accommodate 5,200 cows (Miao and Jiang, 2003). According to MSTC (2005), the construction of concentration demonstration

[5] To ensure raw milk supply, Ministry of Agriculture of China has launched several initiatives to help ensure raw milk supply such as a dairy cattle genetic plan to improve cow genetic through the use of embryo transplants, major scientific projects to alleviate key technical bottleneck, amendment of the "Grassland Law", and has relaxed the dairy pricing system (Yang, MacAulay and Shen, 2004). However, the key program for ensuring raw milk supply is the construction of dairy cattle concentration centre. Many domestic researchers also argue that China's milk supply will heavily rely on the dairy cattle concentration construction and intensive dairy farm production (Liao, 2003; Yi, 2004; Zhu, Guo and Hu, 2003; Yi, 2005a and 2005b).

centres among the key dairy science and technology projects has accommodated 1.38 million dairy cattle during the past three years, which accounts for 15% of China's total dairy cattle population in 2003.

Many plans also exist for future investments in dairy concentration centres. For example, three 10,000-cattle concentration centres have been announced for construction in Datong, Honggang and Ranghulu districts with a total investment of $634 million in Daqing of Heilongjiang province (HPDRC, 2005). New centres planned for Shijiazhuang of Hebei province will eventually house 60,000 dairy cattle over 2004-2010 (TDCB, 2004). The Lintong district government of Xian in Shaanxi province plans to construct ten standard dairy cattle concentration centres by investing $14.9 million to accommodate 20,000 cows upon their completion in 2006 (CCW, 2005).

Such substantial investments in the development of new suburban dairy farms since the early 1990s, along with planned future investments, has and can be expected to continue to contribute to the dramatic expansion of China's milk production capacity. Whether or not this growth in the suburban production sector will add to increased production primarily through increases in cow numbers, or by enhancing productivity, remains to be evaluated.

Data and Descriptive Statistics for Suburban Dairy farms

The National Agricultural Commodity Production Cost and Return Data Collection published by the State Development Planning Commission (SDPC) provide detailed output and cost information for many farming enterprises in China including milk production. It also provides cost data for *suburban* livestock farms, from which the cost data for suburban dairy farms will be used in this study. While the SDPC data for crops have been widely used (e.g., Huang and Rozelle, 1996; Tian and Wan, 2000; Jin et al., 2002), this does not appear to be the case for the livestock data (we are only aware of Rae *et al* (forthcoming) and Ma and Rae 2004). To the best of our knowledge the cost data for suburban livestock production have been never analysed.

The SDPC survey of suburban fresh milk production covers 36 large and medium provincial, municipal and autonomous regional capital cities (except for Tibet) over 12 years (1992-2003). The survey also collected farm data for the dairy industry as a whole (suburban and rural farms) but separate results for non-suburban farms are not published. Prior to publication the cost data were summarized in term 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 specialised households and state-collective farms for the entire dairy sector.

The data include milk yield per cow (kg), by-product value per cow (yuan), farm size (cow numbers), labour inputs per cow (days), concentrate feed and fodder 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.

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 could not discover 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 labour 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.

Table 1 presents the average farm size, yields and major input levels per cow for the two types of suburban dairy farms, and also for the whole dairy farm sample (i.e. suburban plus all other dairy farms). On average, the state-collective suburban dairy farms have much larger herd sizes than the specialist household suburban farms. In 2001-2003, these were 548 and 27 cows, respectively. While the latter farm type increased average herd size by around 40% since 1992-94, average herd sizes for the state-collective suburban farms increased by 90% over the same period. For both state-collective and specialist household farms, those located in suburban areas had somewhat larger average herd sizes than for the whole dairy sector. Averaged over 2001 – 2003, 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 non-suburban farms. This is true for both special household and state-collective farms. The same was true in 1992-94 for state-collective farms. The annual growth rate in yields between these two periods was faster for the suburban special household dairy farms than for the entire sample of such dairy farms (1.84% versus 1.49%), but was slower in the case of state-collective dairy farms (1.63% versus 2.95%). Comparing both types of suburban dairy farms, average yields per cow on the state-collective farms are 17% higher than on special household farms in 2001-2003, and 19% higher in 1992-94.

Average labour inputs per cow were lower on the suburban dairy farms than for the entire dairy farm sample in 1992-94, irrespective of the type of farm. For both farm types, average labour input levels were similar in the suburban and entire farm samples, however, in 2001-2003. Between these time periods, labour usage per cow declined substantially. The average labour input per cow was very similar for both special household and state-collective suburban dairy farms, in either time period. Capital inputs per cow were also lower for both kinds of suburban dairy farm, in comparison with average capital inputs for the entire sample of farms, in 1992-94. By 2001-2003, however, capital usage on the suburban dairy farms exceeded that for the whole industry. By this time, the state-collective suburban dairy farms were much more capital intensive than were the suburban special household farms, by a factor of about three, indicative of a much faster rate of capital accumulation per cow on the former farms.

Average feed inputs per cow on the state-collective suburban dairy farms were higher than for the whole industry in 1992-94, but were rather similar (but still higher for grains and fodder) by 2001-2003. In contrast, feed usage per cow on the special household suburban dairy farms averaged less than for the whole industry in 1992-94, 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 1992-94 and 2001-03. Over this time period, for both types of suburban dairy farm, 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 yield per cow as a measure of feed efficiency, there is some evidence that efficiency has been higher on suburban than on non-suburban dairy farms. Over 2001-2003, for example, this ratio was 0.52 and 0.57 for state-collective and special household suburban 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 dairy farms also vary substantially across suburban 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 state-collective farms averaged from 147 in Shijiazhuang to 3,500 in Wuhan. The range for specialist household farms is much narrower, from just 3 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 (8421 kg and 7939 kg, respectively), while Zhengzhou (Central) and Guangzhou (South) have the lowest (3878 kg and 4000 kg, respectively). Both of these 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, labour and capital inputs. The concentrate feed-to-yield ratio, as measured above, is however lower for both high-yield locations than for the two low-yield areas. A very similar story can be told for the special household suburban dairy 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 higher grain inputs per cow than either of the two 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.

Methodology and Estimation

Over the last twenty years, the literature on productivity measurement has been extended from the standard index-number calculation of total factor productivity (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 behavioural assumptions, such as cost minimization or profit maximization, to provide a valid representation of the underlying production technology (Brummer, Glauben and Thijssen, 2002). In this analysis of productivity in China's dairy industry, we employ the input distance function methodology.

Define the input set as $L(\mathbf{Y}, X)$, which is the set of all possible input vectors **X** from which it is technically feasible to produce at least the output vector **Y.** The input distance function $D^I(\mathbf{X}, \mathbf{Y})$ identifies the least **X** necessary to produce **Y** defined according to $L(\mathbf{Y}, X)$. The input distance function identifies the maximum possible contraction of the input vector that can occur while maintaining the output vector Y:

(1) $D^I(\mathbf{X}, \mathbf{Y}) = \max\{\rho : (\mathbf{X}/\rho) \in L(\mathbf{Y}, X), \rho > 0\}$

Technically inefficient components of $L(\mathbf{Y}, X)$ will have $D^I(\mathbf{X}, \mathbf{Y}) > 1$, while technically efficient allocations will have $D^I(\mathbf{X}, \mathbf{Y}) = 1$. Further, $D^I(\mathbf{X}, \mathbf{Y}) = (1/TE_I) \geq 1$, where TE_I measures input-based technical efficiency. As in Brummer, Glauben and Thijssen (2002), differentiating $\ln D^I(\cdot) + TE$ with respect to time t allows measurement of growth rates for technological progress and technical efficiency. This can serve a basis for the later decomposition of total factor productivity into technical efficiency and technological change components. The input distance function is also homogeneous of degree +1 in inputs, non-decreasing in inputs and non-increasing in outputs (Khumubakar and Lovell, 2000).

We assume that the distance function can be approximated by the translog functional form. As $D^I(\mathbf{X}, \mathbf{Y})$ is unobservable, we make use of the homogeneity property and arbitrarily choose one of the inputs so that:

(3) $\ln(D^I(X,Y)/X_1) = TL^I(\mathbf{X}^*, \mathbf{Y})$

where $X^* = X/X_1$. Re-arranging (3) gives:

(4) $-\ln X_1 = TL^I(\mathbf{X}^*, \mathbf{Y}) - \ln(D^I(\mathbf{X}, \mathbf{Y}))$

For farm *i* at time *t* it can be assumed that $\ln D^I_{it} = u^I_{it}$ if technical efficiency (*TE*) is modelled as $TE^{it} = e^{-u_{it}}$ (Grosskopf *et al.*, 1997; Coelli and Perelman, 1999 and 2000; Karagiannis, Midmore and Tzouvelekas, 2004). Therefore an estimable model can be written as:

(5) $-\ln X_{1it} = TL^I(\mathbf{X}^*_{it}, \mathbf{Y}_{it}) - u_{it} + v_{it}$

Equation (5) is a stochastic input distance function model with a two-part error terms representing deviations from the frontier and random error. As a result, it can be estimated econometrically using maximum likelihood techniques by assuming that υ^I_{it} are independently and identically distributed random variables, $N(0, \sigma^2_v)$, and u^I_{it} are assumed to measure inefficiency, independently distributed according to a distribution that is trancated at zero, $N(0, \sigma^2_u)$. Our complete input distance stochastic frontier model is:

$$(6)\quad -\ln x_{1it} = \alpha_0 + \sum_{k=1}^{2}\alpha_k \ln y_{kit} + \sum_{j=2}^{5}\beta_j \ln x^{*}_{jit} + + \frac{1}{2}\sum_{k=1}^{2}\sum_{l=1}^{2}\alpha_{kl} \ln y_{kit} \ln y_{lit}$$
$$+ \frac{1}{2}\sum_{j=2}^{5}\sum_{g=2}^{5}\beta_{jg} \ln x^{*}_{jit} \ln x^{*}_{git} + \sum_{j=2}^{5}\sum_{k=1}^{2}\delta_{jk} \ln y_{kit} \ln x^{*}_{jit}$$
$$+ \sum_{j=2}^{5}\theta_j t \ln x^{*}_{jit} + \sum_{k=1}^{2}\varepsilon_k t \ln y_{kit} + \gamma t + \eta t^2$$

where *ln* denotes the natural logarithm, $i = 1,2,\cdots,N$ indexes the regional locations; y_{kit} are outputs and x^{*}_{kit} are inputs as defined previously; and $t = 1,2,\cdots,T$ indexes the annual observations over time. The regularity conditions associated with the input distance function require homogeneity of degree one in input quantities and symmetry, which imply the following restrictions on the parameters of equation (6).

$$(7)\quad \sum_{j=1}^{5}\beta_j = 1, \sum_{j=1}^{5}\beta_{jg} = \sum_{j=1}^{5}\delta_{jk} = \sum_{j=1}^{5}\theta j = 0, \alpha_{kl} = \alpha_{lk} \;\; and \;\; \beta_{jg} = \beta_{gj}$$

As previously explained, the homogeneity restrictions are imposed by dividing all input quantities on the right-hand side of equation (6) by the quantity of the input chosen as *numeraire* (here x_1). We define the technical inefficiency term, u_{it}, as a function of both time (t) and locational dummy variables (D_i):

$$(8)\quad u_{it} = \phi_0 + \phi_1 t + \sum \phi_{2i} D_i$$

Since there are serious econometric problems with two-stage formulation estimation (Kumbhakar and Lovell, 2000, pp264), we simultaneously estimate the parameters of equations (6) and (8). The likelihood function of the model is presented in the appendix of Battese and Coelli (1993). 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. 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, Midmore and Tzouvelekas (2004).

The input distance function model (6) – (8) 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 non-suburban 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 is less susceptible of input endogeneity bias than the normal model (Brummer, Glauben and Thijssen, 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 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.

Results and Discussion

Model specification tests were undertaken to indicate whether the state-collective farm data and that for the specialised 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 1 for the suburban sample. These provided statistically significant support for estimating separate models for 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. This was rejected by the test referred to above – note also the significance of the specialized household intercept dummy variable. The separately-estimated input distance functions for both farm types are found to be well-behaved in that, at the point of approximation, they are non-increasing in outputs and non-decreasing in inputs. The estimated variances of the one-sided error terms are 0.008 and 0.010 for state-collective dairy farms and specialized household dairy 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 the existing differences in the degree of technical efficiency (Karagiannis, Midmore and Tzouvelekas, 2004).

Estimates of TFP growth and its decomposition into technical efficiency and technical change components for state-collective and specialised household suburban dairy farms are displayed in tables 4 and 5 respectively. Mean TFP annual growth rates over 1992-2003 are 0.91% for state-collective farms and 2.04% for specialist household farms. The annual rate of technical change is higher (2.57% and 4.96% respectively) meaning that on average, suburban dairy farms have fallen further behind the advancing technical frontier (that is, technical efficiency growth rates are negative). Thus technical efficiency, measured as the ratio of actual to frontier output, has declined on average from 82% to 68% for state-collective farms, and from 88% to 64% for specialist household farms, over the 1992-2003 period.

Considerable variation in productivity performance exists across cities. TFP growth rates range between -3% and 3.85% for state-collective farms, and between -2.3% and 8% for the specialist households. For example, in some suburban areas (e.g., Beijing, Nanjing, Hefei, Wuhan, and Xian), annual TFP growth exceeds 3%, and these all benefit from annual technological change of 3% or more. Even higher TFP annual growth rates are estimated for specialist household farms in some cities, for example, those in Huhehaote, Shenyang, Changsa and Chengdu all exceed 5%, with annual rates of technical change above 6% and as high as 12%. This pattern of productivity change does not always hold, so that fast technological change does not always result in rapid or even positive TFP growth. For example among the state-collective farms, although they have fairly high technical change (e.g. Hangzhou, Jinan, Nanning, Guiyang, Kunming and Wulumuqi), their TFP growth rates are 1% or less and even negative (Nanning and Guiyang). A finding that is consistent over nearly all cities, for both state-collective and specialist household farms, is negative growth in technical efficiency, so that farms on average are falling further behind the advancing production frontier.

What about productivity growth in some of the major milk producing suburban locations? We will focus on state-collective farms in Beijing, Tianjin, Shanghai, and Wulumuqi because their production shares of state-collective farms are relatively high (7.3%, 5.2%, 8.0%, 14.3% and 12.7% of national total state-collective farm production, respectively) and specialist farms in Huhehaote of Inner Mongolia Municipality (where specialized household accounts for 5.2% of national total specialized household output in 1999-2001), Harbin of Heilongjiang province (13.6% of national output) and Yinchuan of Ningxia Municipality (6.6% of national output). In all of these localities the rate of technical change exceeds the average for the relevant farm type, although there are other cities with even higher rates of technical advance. TFP growth is also higher than the mean levels for each of these localities with the exception of Harbin where the negative growth in technical efficiency is amongst the worst in the entire sample.

Table 6 shows technical efficiency levels (the ratio of actual to frontier output) on both suburban state-collective and suburban specialized household dairy farms, subject to our earlier caution on the possibility of downward bias in these estimates. As implied by the negative rates of growth of technical efficiency reported in Tables 4 and 5, mean levels of technical efficiency have fallen since 1992. By 2003, mean technical efficiency across all cities in our sample was only 68% on state-collective farms and 64% on specialist household farms. There also appears to be substantial variation in technical efficiency across cities for both types of dairy farms. Only in Beijing (state-collective farms) has production remained very close to frontier output. Other major cities in the state-collective sample, Tianjin and Shanghai, were very close to the frontier in 1992 but have since fallen behind. Among the major producing cities in the specialist household sample, only Huhehaote remains near the frontier, while technical efficiency levels in Harbin and Yinchuan have fallen to around 50% of potential.

Our results indicate wide variation in the production performance of dairy farms across cities. While several reasons for such variation can be postulated, we found it impossible to construct relevant city-specific variables. Therefore we were forced to model city-specific effects through the use of dummy variables. However, based on field experience and other published studies, some general conclusions may be made. First, the breed composition of cow herds can be one of the most important determinants of performance. Around one third of dairy cattle in China now are

Holstein breed and the annual net increase of this breed of cow is about 0.26 million heads (Yi, 2005b). These high-quality cows are not evenly distributed over cities that therefore contribute to substantial yield variation. For example, per cow yields on state-collective suburban farms were over 8,400 kg in Beijing but less than 3,900 kg in Zhengzhou in 2003. The latter city also experienced inferior growth rates of TFP, TE and TC compared with Beijing (Table 4) and a level of technical efficiency about half that of Beijing in 2003 (Table 6). Second, farmer credit constraints imposed by the banking system could prevent small householders from investing in new dairy farm technologies (Findlay et al., 2003). This could help explain the wide variation in the negative technical efficiency growth rates across the specialised household suburban farms (Table 5). Third, policy priorities have encouraged a great deal of investment, adoption of new technologies and the import of high-quality dairy cows within the suburban dairy industry, all of which might reasonably be expected to be productivity-enhancing. Heilongjiang province has been identified as the 'number one of raw cow milk producers' by the Ministry of Agriculture of China (MOA, 2003), and therefore both central and provincial governments have made substantial investments in new dairy cattle farm programs (Xue, 2005).[6] Financed by the World Bank, there is US$190 million available to import cows and to purchase apparatus and facilities for the construction of dairy cattle concentration centres for specialized households (WBPMO, 2004). Fourth, local climates and roughage resources (e.g., lucerne hay) also evidently affect productivity performance of dairy farms across the country. Normally, the south is not ideally suited to cow milk production and yields

[6] According to our information the construction of dairy concentration centres has at least produced some impact on the local dairy farm production performance in Taiyuan, Huhehaote, Harbin and Xian. We cannot be sure whether it has also happened to other cities because we have not got any such information for them. It should be noted that the construction of concentration centres is mainly for specialist dairy farms since state-collective dairy farms are already sizable.

are also low. For instance, the yield per cow in the south and southwest locations of Table 2 are generally well below yields in other regions.

Given recent activity and emphasis on developing dairy production in suburban areas, is this likely to increase overall average productivity growth in China's dairy sector? From our econometric distance function results using the whole-industry sample (Appendix 2) we computed comparable measures to those discussed above for the suburban sample (Appendices 3-6). Some results are summarised in table 7. We find that the rate of technical change over the past decade has been substantially faster on the suburban farms than for the industry as a whole. For the state-collective farms, technical change advanced at the annual rate of over 2.5% in the suburban subsector compared with around 1% within the whole industry. This difference was even greater for the specialist household farms, with annual growth rates of nearly 5% compared with about 1.5% on such farms in the whole industry sample. From this evidence we conclude that technical change in the suburban subsector has proceeded more quickly than on dairy farms outside of the suburban areas. Such a result is no doubt due in part to the new investments within the suburban dairy subsector and the new technologies that accompany such investments. Despite their superior performance with respect to technological advancement, suburban dairy farms do not necessarily exhibit more rapid growth in total factor productivity. This is shown by the specialist household results where mean TFP grew by 2% per year on the suburban farms compared with 2.3% for specialist household farms across the whole industry. On state-collective farms, though, annual TFP growth in the suburban subsector (0.9%) exceeded that for the whole industry (0.25%). A reason for this is that, since 1992, mean technical efficiency has declined more rapidly on suburban farms compared with the industry as a whole. This is perhaps not surprising given the rapid expansion of the industry especially in suburban areas, adoption of new and perhaps unfamiliar or sub-optimal technologies, the accompanying experimentation and perhaps mistakes on the part of suburban farmers and investors, and the presence of some cautious or slow adopters.

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 centres' have involved considerable national and international investments 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 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, and have fallen further behind. 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- and non-adopters falling behind. The low technical efficiency on suburban dairy farms is probably also influenced by the fact that milk production, while still relatively small, 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 favour certain localities and farm types over others for new investments.

There appears to be considerable scope for improving 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 total factor productivity growth is to more closely approach the rate of growth in technical change

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 equation – 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.

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Table 1. Comparisons of Farm Size, Yields and Major Input Levels Per Cow: Suburban and all dairy farms

Periods/Types	Farm Size (head)	Yield (kg)	Labour (day)	Grains (kg)	Other Fine Feed (kg)	Fodder (kg)	Capital (Yuan)
State-Collective Dairy Farms							
1992-1994:							
Suburban (1)	288	5408	99	2213	891	4697	323
All farms (2)	208	4652	107	1981	726	3422	351
(1)/(2)-1	0.38	0.16	-0.07	0.12	0.23	0.37	-0.08
2001-2003:							
Suburban (3)	548	6255	64	2222	1040	13790	1103
All farms (4)	512	6041	64	2143	1041	12778	1071
(3)/(4)-1	0.07	0.04	-0.00	0.04	0.00	0.08	0.03
1992-2003:							
Suburban (5)	396	5798	77	2262	945	11465	709
All farms(6)	340	5373	80	2117	809	10189	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	4553	95	1619	733	2834	143
All farms (8)	15	4576	113	1880	829	3001	160
(7)/(8)-1	0.26	-0.01	-0.16	-0.14	-0.12	-0.06	-0.11
2001-2003:							
Suburban (9)	27	5366	66	2171	863	7392	374
All farms (10)	24	5229	67	2134	946	7436	326
(9)/(10)-1	0.13	0.03	-0.02	0.02	-0.09	-0.01	0.15
1992-2003:							
Suburban (11)	23	4898	83	1961	732	5279	236
All farms (12)	22	4854	86	1958	833	6227	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	5408	99	2213	891	4697	323
SHHD (14)	19	4553	95	1619	733	2834	143
(13)/(14)-1	14.2	0.19	0.05	0.37	0.22	0.66	1.27
2001-2003:							
Stat/Coll.(15)	548	6255	64	2222	1040	13790	1103
SHHD (16)	27	5366	66	2171	863	7392	374
(15)/(16)-1	19.3	0.17	-0.04	0.02	0.20	0.87	1.95
1992-2003:							
Stat/Coll.(17)	396	5798	77	2262	945	11465	709
SHHD (18)	23	4898	83	1961	732	5279	236
(17)/(18)-1	16.1	0.18	-0.07	0.15	0.29	1.17	2.00

Data source: Agricultural Commodity Production Cost and Return Survey Handbooks, 1993-2004.
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.

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)	Labour (day)	Grains (kg)	Other Fine Feed (kg)	Fodder (kg)	Capital (Yuan)
Suburban State-collective Dairy Farms								
Zhengzhou	Centre	220	3878	49	1320	1180	13000	399
Guangzhou	South	330	4000	36	2530	1280	10800	1210
Guiyang	South West	3400	5500	90	3096	4	16500	1865
Lanzhou	West	330	5949	24	2156	817	12423	963
Xining	West	594	6125	58	1948	1947	16229	573
Hangzhou	South East	882	6414	75	2966	817	17642	518
Changchun	North East	380	6540	132	3078	720	12521	324
Hefei	South East	902	6667	73	1324	567	15888	909
Jinan	East	1184	6750	15	3429	605	12962	2203
Wuhan	Centre	3500	6940	65	2430	1050	12900	1184
Shijiazhuang	North	147	7044	74	1450	1450	17683	1687
Shanghai	East	216	7494	55	2722	1173	17400	875
Wulumuqi	Far West	1138	7939	50	2259	1506	11805	3201
Beijing	North	512	8421	24	2154	2342	5423	952
Suburban Specialized Household Dairy Farms								
Kunming	South West	11	3770	43	1000	557	3696	175
Nanning	South	9	4424	42	1553	1650	9256	258
Xian	West	2	4861	118	2080	367	1399	182
Changsha	South	15	4900	59	2800	700	2480	1450
Qingdao	East	3	5000	68	1784	957	5127	238
Yinchuan	West	43	5116	17	3598	1136	4779	167
Zhengzhou	Centre	8	5169	66	1625	765	10000	356
Chengdu	South West	17	5290	61	2151	944	19599	291
Harbin	North East	6	5334	91	2803	91	3467	736
Taiyuan	Centre	9	5362	70	1630	1630	12000	270
Shenyang	North East	30	5705	39	1422	356	10160	66
Huhehaote	North	12	6003	56	2274	1048	6955	96
Jinan	East	8	6169	77	2469	675	9280	339
Beijing	North	171	6409	38	2368	971	6630	422
Tianjin	North	152	6454	42	2252	1051	9664	220

Data source: Agricultural Commodity Production Cost and Return Survey Handbooks 2004.

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 efficiency model were not displayed. X_1 is used as a numeraire.

Table 4. 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]	1992-03	12	0.91	-1.66	2.57
Beijing	1992-03	11	3.16	0.16	3.00
Tianjin	1992-03	9	1.06	-1.63	2.69
Shijiazhuang	1992-03	12	1.38	-1.29	2.67
Changchun	1992-03	8	-1.58	-3.76	2.17
Harbin	1992-96	5	-2.12	-2.56	0.45
Shanghai	1992-03	12	1.26	-1.87	3.13
Nanjing	1992-03	10	3.22	-0.07	3.29
Hangzhou	1996-03	8	1.01	-3.10	4.11
Hefei	1992-03	9	3.08	0.54	2.53
Jinan	1994-03	10	0.09	-3.42	3.52
Zhengzhou	1992-03	11	-1.98	-3.36	1.39
Wuhan	1994-03	10	3.67	0.44	3.23
Guangzhou	1992-03	9	-1.74	-4.61	2.88
Nanning	1992-01	8	-3.01	-5.88	2.87
Chongqing	1992-03	7	1.53	-1.20	2.73
Chengdu	1996-01	5	3.42	-0.26	3.68
Guiyang	1992-03	7	-0.15	-3.83	3.68
Kunming	1992-99	7	0.88	-2.67	3.55
Xian	1992-03	12	3.85	0.88	2.97
Lanzhou	1992-03	8	2.47	-0.33	2.81
Xining	1993-03	11	0.00	-2.17	2.18
Wulumuqi	1996-03	7	0.81	-3.05	3.86
Dalian	1994-03	10	0.65	-2.01	2.66
Ningbo	1992-03	11	0.04	-2.44	2.48

Note: 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 year and ending year of observations. The table only keeps those having 5 and more observations.

[a] TC estimated at mean values of all variables.

Table 5. 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]	1992-03	12	2.04	-2.92	4.96
Tianjin	1992-03	10	-0.62	-4.12	3.49
Taiyuan	1999-03	5	1.86	-9.11	10.98
Huhehaote	1998-03	6	7.01	-2.19	9.20
Shenyang	1992-03	9	5.99	-0.10	6.09
Harbin	1992-03	12	1.46	-5.59	7.05
Fuzhou	1995-03	9	1.99	-5.25	7.24
Jinan	1995-03	9	3.24	-3.33	6.57
Changsa	1998-03	5	7.71	-7.23	14.94
Chongqing	1993-03	8	-2.33	-2.14	-0.19
Chengdu	1996-03	6	8.03	-3.86	11.89
Kunming	1994-03	9	1.30	-3.77	5.07
Xian	1993-03	9	1.04	-7.80	8.84
Yinchuan	1992-03	11	2.11	-4.36	6.47
Qingdao	1993-03	7	3.70	-6.15	9.85
Ningbo	1992-97	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 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] TC estimated at data means.

Table 6. The Change of Technical Efficiency (TE) on Suburban Dairy Farms in China

Suburban State-Collective Dairy Farms				Suburban Specialized Household Dairy Farms			
City	1992-03	1992	2003	City	1992-03	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				

Source: model results.
Note: The italic numbers are not in the year shown but either previous or after to demonstrate the trend of technical efficiency change over time. The table only keeps those that have 5-year or over observations.

[a] Simple unweighted means of all available regions.

Table 7. 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
		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
		Specialised Households			
Suburban	2.04	-2.92	4.96	0.88	0.64
All farms	2.33	0.78	1.55	0.82	0.90

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

Appendix 1. 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% significant level.

Appendix 2. The Estimates of Input Distance Function for All Dairy Farms in China

Variables in log format	State and Collective Dairy Farms		Specialized Household Dairy Farms	
	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
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 efficiency model were not displayed. X_1 is used as a numeraire.

Appendix 3. 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]	1992-03	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: 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 running model, we dropped Jiangxi, Sichuan, Yunnan and Ningxia because they have less than 3 observations.

[a] TC estimated at data means

Appendix 4. 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]	1992-03	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 running model, we dropped Beijing, Shanghai, Zhejiang, Jiangxi and Guanxi because they have less than 3 observations in either near 2003 or near 1992.

[a] TC estimated at data means.

Appendix 5. The Change of Technical Efficiency (TE) on All Dairy Farms in China

All State and Collective Dairy Farms				All Specialized Household Dairy Farms			
Province	1992-03	1992	2003	Province	1992-03	1992	2003
Mean [a]	0.82	0.87	0.80	Mean [a]	0.88	0.82	0.90
Beijing	0.98	0.98	0.98	Tianjin	0.89	0.90	0.98
Tianjin	0.94	0.96	0.94	Hebei	0.76	0.83	0.97
Hebei	0.96	0.97	0.95	Shanxi	0.93	*0.59*	0.92
Neimeng	0.94	0.94	-	Neimeng	0.98	0.98	0.95
Liaoning	0.79	-	0.78	Liaoning	0.91	-	0.99
Jilin	0.99	0.99	0.99	Jilin	0.77	0.87	-
Shanghai	0.98	0.99	0.98	Heilongjiang	0.98	*0.99*	0.99
Jiangsu	0.82	0.87	0.85	Anhui	0.80	0.54	0.75
Zhejiang	0.91	-	0.89	Fujian	0.90	-	0.90
Anhui	0.74	*0.79*	0.78	Shandong	0.97	-	0.93
Fujian	0.79	-	0.77	Henan	0.82	*0.77*	0.78
Shandong	0.83	0.91	0.77	Hunan	0.87	-	0.81
Henan	0.62	0.70	0.59	Chongqing	0.78	-	0.76
Hubei	0.69	0.71	0.68	Sichuan	0.88	-	0.88
Hunan	0.69	0.73	-	Yunnan	0.95	-	0.97
Guangdong	0.58	*0.65*	0.57	Shaanxi	0.86	*0.91*	0.78
Guangxi	0.74	-	0.68	Ningxia	0.96	-	0.92
Hainan	0.41	-	0.42	Xinjiang	0.78	-	0.99
Chongqing	0.80	-	0.78				
Guizhou	0.60	0.71	0.61				
Shaanxi	0.94	0.80	0.93				
Gansu	0.80	0.91	0.79				
Qinghai	0.83	-	0.82				
Xinjiang	0.99	*0.99*	0.99				

Source: directly model results.
Note: The italic numbers are not in the year shown but either previous or after to demonstrate the trend of technical efficiency change over time.

[a] Simple means of all available provinces.