Total Factor Productivity Change in Dairy Production in Southern Chile: Is Farm Size Significant?

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Selected Poster prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.

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ABSTRACT: This paper examines the connection between total factor productivity change and dairy farm size in Southern Chile, a translog stochastic production frontier is estimated using an unbalanced panel for 2005-2009 including 417 farms and 1,186 observations. Descriptive analyses and econometric evidence indicate that the farms exhibit decreasing returns to size, productivity gains through technical efficiency or management improvements are limited while technological progress is rather low; thus, investments in research appear promising. Although the findings reveal that farm size is not associated with productivity growth, a clear positive association between farm size and net income is found.

Keywords: total factor productivity; stochastic frontiers; dairy farm size

1. INTRODUCTION

The relationship between productivity and farm size has attracted the attention of economists for a long period of time (e.g., Berry and Cline, 1979) and has recently resurfaced as a topic of interest particularly in the context of poverty alleviation within the Millennium Development Agenda (Hazell et al., 2007; UN, 2008; World, 2008). Moreover, for developing countries facing an increasingly globalized economic environment, productivity growth and rising competitiveness is essential to insure the prosperity of agriculture and thus contribute to poverty reduction (Sandrey and Scobie, 1994; Ravallion and Datt, 1996; Rosegrant and Hazell, 2000; Pinstrup-Andersen, 2002; Ruttan, 2002; Thirtle et al., 2003).

The rising globalization of agricultural markets is leading to persistent competition across and within countries and this phenomenon presents both challenges and opportunities to the farming sector. In this context, there has been a rekindling of interest on the contributions that agriculture can make in the economic development of emerging nations in general and the role of small farms in this process in particular. Moreover, analysts have begun to question the future viability of small farms and whether agricultural development policy actions should stress small or large operations (IFPRI, 2005).

Analysis of productivity growth over time, and productivity differentials between countries, regions and farms differing in size have been important subjects of formal analysis in agricultural and development economics for several decades. Furthermore, rapid rates of income and population growth are expected to double the demand for agricultural products over the next 50 years. Hence, substantial gains in farm productivity will be needed to keep up with this expanding demand (Ruttan, 2002).

Despite the importance of productivity growth, much of the work done at the farm level has focused primarily on the technical efficiency (TE) component of farm productivity (e.g., Bravo-Ureta et al., 2007). Therefore, the general purpose of this paper is to measure and examine the Total Factor Productivity Change (TFPC) of a sample of Chilean dairy operations, a farming activity that plays an important role in the country's agricultural economy particularly in the Southern Region. The specific objective is to decompose TFPC and then to examine the connection between these different components and farm size.

National level data, obtained from the 1996-97 and 2006-07 Census of Agriculture (INE, 2010) reveals considerable transformation in the structure of dairy farming. The data in Panel-A of Table 1 shows an overall reduction in the national dairy herd from 618,000 to 495,000 cows over the 10 year period. The biggest loss is for farms with less than 99 cows (50.1% decline) and then for farms that have between 100 and 199 cows (23.8% decline). By contrast, farms with 200 cows and above enjoyed a 56.8% average increase in herd size. If we now look at Panel-B in Table 1, we observe a drop in the total number of dairy farms from 49,154 in 1996-97 to 19,739 in 2006-07. The change in farm numbers goes from -63% for the 1-19 cow group to a positive 149% for farms with 500 or more cows. In sum, these data clearly show major changes in the structure of Chilean dairy production over a relatively short time period. Thus, the intention of this paper is to shed light on the connection between farm size and productivity growth so as to derive inferences on what might be expected in terms of the future structure of dairy farming in Southern Chile, the country's dominant milk production area.

The data used in the study is a unique unbalanced panel for the five year period between 2005 and 2009 for 417 farms mainly located in the Southern Regions of Los Lagos and Los Ríos, with a few farms located just to the north of these regions. The data was obtained from the TODOAGRO Farm Management Center.[1] The stochastic production frontier framework along with the methodology introduced by Bauer (1990) as refined by Kumbhakar and Lovell (2000) is used to decompose TFPC into Scale Efficiency Change (SEC), Technological Change (TC), TE Change (TEC) and Allocative Efficiency Change (AEC).

The plan for the remainder of the paper is as follows. Section 2 provides a brief review of relevant published productivity studies followed by a discussion of the data in Section 3. The methodological framework is explained in Section 4, the empirical models and results are presented in Section 5 and the last Section contains some concluding remarks.

2. REVIEW OF LITERATURE

The dairy industry in many countries has been subject to considerable protection over the years from a variety of governmental policies. However, in this rapidly globalizing environment, markets are less protected which places a premium on competitiveness and farms must be prepared to make the best use of existing technologies and also to innovate and adopt new practices (Blayney and Gehlhar, 2005).

In the Chilean case, the dairy sector received a relatively high degree of protection in the early 1990s, and was until recently more heavily protected than other commodities. However, the extent of this protection has declined overtime and is now limited to occasional import tariffs imposed as safeguards primarily in response to sporadic subsidies

[1] More details can be found in www.todoagro.cl.

provided by the Argentinean Government to their dairy producers. Moreover, Chile has emerged as a net exporter of dairy products and thus the prevailing domestic price is the world market price (OECD, 2008).

Recognizing the challenges and opportunities associated with opening up the economy, the Chilean government has reoriented commodity specific support towards broader programs designed to improve managerial performance in order to increase farm competitiveness. One such effort has been the introduction of Farm Management Centers (FMCs) whose primary function is the training of producers and the generation of information in order to improve managerial ability, and the promotion of alternative marketing options (Ceges Chile, 2011). A related effort has been the promotion of different consortia, which are private organizations created to coordinate efforts from various economic agents to enhance the competitiveness of strategic agricultural subsectors such as dairy production (Álvarez et al., 2010).

Researchers have spent considerable effort in examining managerial performance in agriculture, which is often proxied by TE (Mundlak, 1961) and much of this work has focused on dairy farming (Bravo-Ureta et al., 2007). However, only a limited number of micro studies have gone beyond the TE component of productivity. Exceptions where efforts have been made to provide a more comprehensive analysis of production and productivity growth include the work by Lachaal (1994), Ahmad and Bravo-Ureta (1995; 1996) and Tauer (1998) for the US, Richards (1995) for Canada, Piesse et al. (1996) for Yugoslavia, Brümmer et al. (2002) for three European countries, Newman and Matthews (2007) for Ireland, and more recently Kumbhakar et al. (2008) for Norway, and Mosheim and Lovell (2009) again for the US. However, the inclusion of Allocative Efficiency (AE) in productivity growth analyses has been very limited and thus it is useful to review briefly the main studies that have done so.

It appears that the first published study to examine AE in dairy production, along with technical and scale efficiencies within a frontier framework, is by Bailey et al. (1989). These authors, using cross sectional data for a sample of 68 Ecuadorian dairy farms for 1986, found that technical inefficiency ranged from 11.8% to 12.8% and that large and medium-sized farms exhibited higher AE than small farms. However, most farms in the sample were producing below the optimum level of output. Dawson and White (1990) used stochastic production frontiers and data for three years (1984-1985 to 1986-1987) for 306 dairy farms from England and Wales to analyze AE and TE after dairy production quotas were introduced in April 1984. The key results are that producers were able to adjust the AE of variable inputs while TE remained fairly constant over the period of analysis.

Bravo-Ureta and Rieger (1991) extended the deterministic Kopp and Diewert framework to a stochastic production frontier model and, invoking the self duality of the Cobb-Douglas technology, examined TE, AE and economic efficiency (EE) for a cross sectional sample including 511 New England dairy farms for 1984. The authors reported an average level of EE equal to 70% while average TE and AE where very similar at 83% and 85%, respectively. No clear association between efficiency, farm size, education, extension and experience was found.

Kumbhakar et al. (1991) developed a generalized production frontier model to measure TE and AE for a cross sectional sample of US dairy farms for 1985. Their results revealed that education is positively associated with TE and that larger farms are relatively more profitable while exhibiting higher TE and AE than smaller ones.

Tauer (1993) used Data Envelopment Analysis (DEA) to investigate short and long-run TE and AE for 395 New York dairy farms using data for 1990. The analysis revealed that on average, AE was higher in the short run than in the long run, but the opposite was the case for TE. In addition, stanchion barns were found to be as efficient as milking parlors while milking more than twice daily made no contribution to efficiency. In another DEA study, Hansson and Öhlmér (2008) examined the connection between operational practices and efficiency using unbalanced panel data for Swedish dairy farms. The results showed that managerial practices can have differential impacts on long-run TE, long-run AE as well as on short-run EE.

Maietta (2000) used a shadow cost model to obtain EE, AE and TE using a panel data set for Italian dairy farms. This author reports that costs are on average 69% higher than what they should be primarily as a result of technical inefficiency. Moreover, the author finds that technical inefficiency dominates allocative inefficiency and the former increases while the latter decreases as farm size rises.

In sum, several studies have examined different aspects of productivity in dairy farms using a variety of methodologies and data sets. However, the bulk of the work has focused on TE while limited efforts have been reported where TFPC is measured and then fully decomposed using farm level data. Below, we undertake this matter for a large sample of Chilean dairy farms in order to glean possible implications for the future structure of this industry.

3. SETTING OF THE STUDY AND DATA

In Chile, several FMCs are working with different types of farmers. TODOAGRO, created in 1996, is the largest FMC operating in the southern part of the country accounting for 20% of the total milk processed in the country. Although milk is the main output of TODOAGRO's members, other products include commercial grains, beef, potatoes and blueberries. In our case all data is related to milk and milk by-products, thus the output is measured as milk equivalent.

The TODOAGRO data used in this study is an unbalanced panel including 417 dairy farms located mainly in the Los Lagos and Los Ríos Regions (see Figure 1). The data are annual figures covering the years 2005 to 2009 with a total of 1,186 observations. As shown in Table 2, most of the farms in the data set have information for more than one year. More specifically, almost 21% of the farms have data for all five years (435 observations); 16% have data for four years (272 observations); 12% for three years (153 observations); 28% for two years (230 observations); and the rest of the farms have data for only one year (96 observations).

Table 3 presents the distribution of farms per year as well as the mean for all variables included in the production frontier along with other key indicators of farm performance for three groups: the entire sample; the 20% smallest; and the 20% largest farms in terms of milk production measured in 1,000 liters. Defining farm size in terms of output is consistent with the standard microeconomic or production economics textbook definition (e.g., Varian, 1992; Beattie et al., 2009); however, in empirical work authors adopt different definitions and in the case of dairy farming total cows is often used along with milk production (Sumner and Wolf, 2002). In practical terms, these two variables are highly correlated as would be expected (r=0.943 for our data). All variables in monetary terms are originally reported in nominal Chilean Pesos (Ch $) and are then converted to real 2009 Ch $ using the Chilean Consumer Price Index (Banco Central de Chile, 2010) and then expressed in US Dollars using the average exchange rate for 2009 (US $ 1= Ch $559.6).

Overall, the data in Table 3 reveals noticeable differences across variables with respect to the size of the dairy enterprise.[2] The number of farms for the 20% smallest group (largest) goes from 57 (56) in 2006 to 34 (33) in 2005 while the range for all farms combined goes from 282 in 2006 to 167 in 2005. Average milk production per farm ranges from 295,000 liters (L) in 2006 for the smallest quintile to 4,052,000 L in 2009 for the largest quintile with an overall average (for the five year period and all farms) of 1,602,000 L. Average herd size ranges from 69 for the smallest quintile in 2006 to 579 cows in 2009 for the largest quintile with an overall average of 258 cows. Although not shown in Table 3, the smallest farm in the sample has 18 cows in 2006 while the largest has 1,404 in 2009. Therefore, the sample includes significant variability in terms of herd size.

The average number of hectares devoted to the dairy enterprise goes from a minimum of 45 in 2006, to 284 in 2009 with an overall average of 136. Again, although not shown in Table 3, the number of hectares for the individual data exhibits significant variation going from a minimum of 5 ha in 2006 to a maximum of 798 ha in 2005. The Table also shows average milk production per cow where we see no clear trend overtime within each of the three farm groupings. However, productivity per cow for the smallest quintile goes from 3,745 in 2005 to 4,058 in 2009 while these averages are considerably higher for the largest quintile going from 6,521 in 2005 to 6,934 in 2009. This significant difference in productivity per cow is consistent with a major difference in concentrate feed per cow which goes from an average of 675 Kg/cow for the smallest quintile over the five year period to 1,973 Kg/cow for the largest.

The bottom of Table 3 displays cost of production per liter, as reported by TODOAGRO, which excludes interest on capital (borrowed and/or owned), and the costs of land, family labor and management. The overall average cost is US $0.24/L. The lowest cost/L is US $0.189 for the smallest quintile in 2006 while the highest is US $0.303 for the largest quintile in 2008. The Table also presents the average price/L received by producers, again as reported by TODOAGRO making it possible to calculate operational profits/L, which in this study reflect the returns to the excluded inputs just mentioned. The average operational profit/L for the overall sample is US $0.058 ranging from a low of US $0.028 for the

[2] The data available for this study corresponds only to the dairy enterprise within the farms in the data set. Although these farms concentrate on dairy production some other outputs are also produced.

largest quintile in 2009 to a high of US $0.085 for the same group in 2007. The average operational profit/L for the smallest quintile for the 5 years is slightly lower at US $0.053 than the average for the largest quintile at US $0.057.

A final point concerns total operational profits for the three farm groups, reported in the last row in Table 3. According to these figures, the overall average operational profits for the sample is US $91,000 but this indicator, as would be expected, has considerable variability going from a low of US $12,000 for the smallest quintile in 2009 to a high of US $311,000 for the largest quintile in 2007. Figure 2 shows the scatter of farm level operational profits and the number of cows which clearly reinforces the positive relationship between such profits and farm size.

The preceding descriptive analysis suggests that the average cost curve is very flat while farm income grows considerably with farm size. The combined implication of these two points is that the impetus for farm growth stems from the search for income rather than from increasing returns to size. This has been an old debate in the agricultural economics literature (e.g., Upchurch, 1961; Hall and LeVeen, 1978; Berry and Cline, 1979) and is a major motivation for the econometric analysis undertaken in the remainder of this paper.

4. METHODOLOGICAL FRAMEWORK

As indicated earlier, the purpose of this paper is to measure and decompose TFPC and then to examine the connection between the various components and farm size. To tackle this task, we follow the methodological approach presented by Kumbhakar and Lovell (2000). We start by assuming that panel data is available, which is a requirement when analyzing productivity growth at the farm level, and then we write the following stochastic production frontier (SPF) model:

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

where y_{it} denotes output for the *i*-th firm in the *t*-th time period; x_{it} is a $(1\times K)$ vector of inputs and other explanatory variables (e.g., time) for the *i*-th firm in the *t*-th time period; β is a $(K\times 1)$ vector of unknown parameters to be estimated; v_{it} is a random error assumed to follow a normal distribution with mean zero and constant variance ($v_i \sim iid\ N(0, \sigma_v^2)$); and u_{it} is a non-negative unobservable random error which captures the technical inefficiency of the *i*-th firm in period *t*. Thus, TE is modeled as time variant which is a desirable choice when decomposing productivity growth as we do below.

The inefficiency effects, u_{it}, in the stochastic frontier model (equation 1) can be expressed as:

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

where w_{it} is a random variable defined by the truncation of the normal distribution with zero mean and variance σ^2, z_{it} is a $(p\times 1)$ vector of variables which may influence the efficiency of a firm, and δ is a $(1\times p)$ vector of parameters to be estimated.

TE for the *i*-th firm in period *t* is equal to $\exp(-u_{it})$. The term u_{it} cannot be measured directly but it is part of the composed error term. However, the conditional expectation of $\exp(-u_{it})$ can be derived from the composed error term of the stochastic model following

Jondrow et al. (1982) and Battese and Coelli (1988). For the analysis reported below, all parameters of the SPF model are estimated using FRONTIER 4.1 (Coelli, 1996).

Total Factor Productivity Change (TFPC) Decomposition

As is well defined in the literature, output growth is the combination of productivity growth and the growth in inputs or the size effect. Productivity has commonly been defined as the part of output growth that cannot be explained by the growth in inputs, under the assumption that firms are producing on the frontier (Ahmad and Bravo-Ureta, 1995). If inefficiency is ignored, productivity is synonymous with technological change (Morrison, 1999). Nishimizu and Page (1982) were the first to account for technical efficiency change in primal frontiers and thus decomposed productivity growth into Technological Change (TC) and Technical Efficiency Change (TEC) while also incorporating the input or size effect when analyzing output growth. More recently, Kumbhakar and Lovell (2000), following Bauer (1990), have extended the decomposition of TFPC in primal stochastic frontiers by incorporating Scale Efficiency Change (SEC) and Allocative Efficiency Change (AEC).

TC, which is reflected in a jump or upward shift in the production frontier, has received a great deal of attention in the literature for many years following the seminal paper by Solow (1957). TEC is due to improvements in the efficiency with which the firm uses its inputs given the available technology. It is important to note that a firm could increase its productivity, even if there is no TC, by making a more efficient use of its inputs, i.e., by operating closer to its production frontier. SEC measures the contribution of scale economies to productivity change while AEC captures the firm's ability to adjust the mix of inputs so that input price ratios are equal to the ratios of corresponding marginal products (Coelli et al., 2003).

The first question to address in quantifying TFPC using SPFs is the choice of a functional form. Empirical research frequently relies on the relatively simple Cobb-Douglas (CD) functional form. However, given the restrictive nature of the CD, a more flexible alternative that is also commonly used in productivity studies is the translog (TL) (Bravo-Ureta et al., 2007). A TL production function can be specified as:

$$y_{it} = \alpha_0 + \sum_{k=1}^{K} \beta_k x_{kit} + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} x_{kit} * x_{lit} + \sum_{k=1}^{K} \delta_k x_{kit} * T + \lambda_1 T + \frac{1}{2} \lambda_{11} T^2 + v_{it} - u_{it}\ , \qquad (3)$$

where the subscripts *it* refer to the *i*-th firm in time period *t*. The dependent variable is the natural logarithm of output (*y*), x_{it} are the natural logarithm of inputs, the subscript *k* represents the *k*-th explanatory variable, *T* is a smooth time trend that captures TC, v_{it} and u_{it} are random variables as defined in equation (1), and Greek letters represent parameters to be estimated.

The natural logarithm of TFPC between period *T=0* and *T=1* for the *i*-th firm, given a TL functional form (equation 3), can be defined as (Coelli et al., 2003):

$$\ln \frac{\text{TFP}_{i1}}{\text{TFP}_{i0}} = \underbrace{\ln \frac{\text{TE}_{i1}}{\text{TE}_{i0}}}_{\text{TEC}} + \underbrace{\frac{1}{2}\left[\frac{\partial \ln y_{i0}}{\partial} + \frac{\partial \ln y_{i1}}{\partial}\right]}_{\text{TC}} + \underbrace{\frac{1}{2}\sum_{k=1}^{K}\left[\left(SF_{i0} * e_{ki0} + SF_{i1} * e_{ki1}\right) * \left(\ln x_{ki1} - \ln x_{ki0}\right)\right]}_{\text{SEC}}$$

$$+\underbrace{0.5\sum_{k=1}^{K}\left\langle\left[\left(\frac{e_{ki1}}{e_{i1}}-s_{ki1}\right)+\left(\frac{e_{ki0}}{e_{i0}}-s_{ki0}\right)\right]*\left(x_{ki1}-x_{ki0}\right)\right\rangle}_{\text{AEC}}, \quad (4)$$

where TE_{it} is the predicted value of TE for the *i*-th firm in time period *t*, as previously explained; $TC_{i0} = \frac{\partial \ln y_{i0}}{\partial t}$ is the average of the partial derivatives of output (*y*) with respect to *t* for a given firm for two consecutive periods; and s_{kit} is the cost share of the *k*-th input of the *i*-th firm in time period *t*. The calculation of SEC requires values for the partial elasticities of production (e_{it}), and also the scale factor (*SF*) to be estimated at each data point, where $e_{it} = \sum_{k=1}^{K} e_{kit}$ and $SF_{it} = \frac{(e_{it}-1)}{e_{it}}$. Under constant returns to scale, e_{it} is equal to 1, and hence the scale term in equation (4) is equal to 0.

5. EMPIRICAL MODEL AND RESULTS

A TL production frontier, as depicted in equation (3), incorporating six inputs, a time trend and a few environmental dummy variables is estimated to undertake a full decomposition and analysis of TFPC. The dependent variable (y) is milk equivalent in liters (L) per year per farm calculated as the sum of milk sales plus dairy livestock sales divided by the average milk price received by each farm in each year, as calculated and reported by TODOAGRO. This measure of output is similar to what is used in other dairy studies (e.g., Frank, 1998; Reinhard et al., 1999). All inputs are expressed as annual flows per farm. The explanatory variables are defined as follows:

- CO: Total dairy cows;
- LB: Labor equal to total wages paid to hired workers (US$);
- CF: Concentrate feed (Ton);
- FF: Forage feed expenses including the cost of forage produced on farm (US$);
- VE: Veterinary expenses including insemination and veterinary supplies (US$);
- OC: Other costs corresponding to the dairy enterprise including power, fuel and depreciation (US$);
- ZD: Agro-ecological zone Dummies (Zones 1-5 and ZD1 is the excluded category). The classification of each farm into an agro-ecological zone was provided by the TODOAGRO FMC;
- DD: Drought effect Dummy (1=2007-2009, 0 otherwise);
- T: Smooth time trend that captures technological change (1=2005; 2=2006 3=2007; 4=2008; 5=2009);
- v_{it}, u_{it}: Random errors; and
- $\alpha,\beta,\delta,\lambda$: Unknown parameters.

Two variables are included in the inefficiency component of the model, farm size and again the time trend as follows:

- T: Smooth time trend that captures learning by doing;
- T^2: Time squared;
- LD: Land in hectares (ha) to capture farm size; and
- LD^2: Land squared.

The econometric results, presented in Table 4, reveal that of the 40 parameters estimated, excluding the intercept, 16 are significant at the 1% including all six linear parameters for the inputs; five are significant at the 5%; three at the 10%; and 16 are not significant at conventional levels. All variables are normalized by their respective geometric means before estimation; thus, the linear parameters for the inputs represent partial elasticities of production. We should also highlight the fact that the gamma parameter is equal to 0.963 and significant at the 1% indicating that an important share of the variability in output is due to technical inefficiency.

As is well known, the TL has the advantage of being a flexible functional form but a disadvantage is that regularity conditions stemming from economic theory are not globally satisfied and violations are often present; hence, this is an issue that needs to be verified ideally at each data point. The most important regularity condition is monotonicity which requires that marginal products at all points in the data and for all inputs be non-negative (Coelli et al., 2005). As shown in Table 5, the model estimated here (Table 4) is well behaved exhibiting a very low number of violations. The data shown in Table 5 reveals that the number of Cows (CO) are particularly well behaved with only one violation of monotonicity (out of 1,186) while the largest number of violations is for Veterinary Expenses (VE) with 53 which still only represents 4.5% of the total cases.

A parameter of particular importance when examining the connection between farm size and productivity is the function coefficient, a primal measure of economies of size, which is equal to the sum of the partial elasticities of production. To get a broad view of economies of size in the sample, we show in Table 6 the partial elasticities for each input by quintile calculated by averaging individual farm estimates. As is commonly the case in dairy studies (e.g., Bravo-Ureta, 1986; Dawson, 1987; Bravo-Ureta and Rieger, 1991; Ahmad and Bravo-Ureta, 1995 and 1996; Lawson et al., 2004; Kompas and Che, 2006; Moreira et al., 2006; Cabrera et al., 2010; Moreira and Bravo-Ureta, 2010), the largest partial elasticity is for CO ranging from 0.416 for the smallest quintile to 0.379 for quintile II with an overall average of 0.392. The second input in importance with respect to the value of the partial elasticity is Concentrate Feed (CF) with an overall average of 0.178, which is also consistent with previous studies. If we now look at the function coefficient we find that the average value for this parameter is remarkably close across the five quintiles ranging from 0.924 for quintile I to 0.974 for quintile V with an overall average of 0.946. Keeping in mind that constant returns to size (CRS) prevail when the value of the function coefficient is 1.0 we can conclude that this sample is close to exhibiting a CRS technology. Figure 3 shows the scatter of the function coefficient values and milk production for each observation in the sample which further reinforces the CRS finding which in turn is consistent, as one would expect, with the descriptive analysis of the data reported in Section 3 above.

The inefficiency component of the model (Table 4) shows that LD has a positive and significant influence on TE, which means that as farm size increases TE also increases but at a decreasing rate since LD^2 is positive and significant. The same influence on TE is observed for T and T^2; thus, TE is increases over time at a decreasing rate.

The component of productivity that has received most attention in the empirical literature focusing on dairy farming is TE (Bravo-Ureta et al., 2007) and thus we take a brief look at these results before moving to the analysis of TFP. Table 7 contains descriptive statistics for TE scores by quintiles according to milk production and overall. As the data shows, the average TE scores across quintiles are once again very close ranging from 83.7% for quintile I to 94.1% for quintile V showing a slight positive association with farm size. If we look at the extreme points, we see that the lowest level of TE is 20.2% for a farm in quintile I and the highest is 100.0% for a farm in quintile III. The overall mean for the entire sample is 90.2% which is a few points higher than the 83.3% calculated from 32 dairy farm studies that used stochastic frontiers as reported by Moreira and Bravo-Ureta (2009) in their recent meta-analysis paper.

We now turn to the last part of the analysis which focuses on the decomposition of TFPC based on equation (3) discussed in Section 4. We calculate two measures of TFPC: 1) TFPC1 which includes TEC, TC and SEC; and 2) TFPC2 which is equal to TFPC1 plus AEC. To calculate the latter we need to compute the share for each input on total costs and such computations are straight forward except for CO.

To calculate the shares for cows we need to obtain an annual user cost per cow which includes depreciation and opportunity cost of the capital invested on the animals. Depreciation is calculated as: (Average Heifer Price – Average Cull Cow Price) divided by the useful life of a dairy cow estimated at 3.5 years. The opportunity cost of capital is computed as (Average Heifer Price + Average Cull Cow Price) divided by 2 and all of this is multiplied times the average annual real interest rate paid on deposits and the cost of borrowing as reported by the Chilean *Superintendencia de Bancos e Instituciones Financieras* (2010).[3] The heifer and cull cow prices are included in the TODOAGRO data base.

Table 8 shows average TFPC1 and TFPC2 along with the various components by quintile and overall. The data reveals a fair amount of variability across components and TFPC for the various quintiles. Focusing first on TFPC1 for the entire sample, we observe that the dominant component is TC (0.275%), followed by SEC (-0.022%) and TEC (-0.066%) which yields an average annual rate of growth in TFP equal to 0.186%. The lowest rate of growth according to TFPC1 is for the smallest group (-1.795%) while the highest is for quintile IV at 1.028%.

If we now look at TFPC2 for the entire sample the data shows an important role for AEC of 0.442%. The average annual rate of growth in TFP goes up to 1.003% for the quintile IV while the lowest rate of growth is for the quintile II (0.193%), with an overall average of 0.628%. Thus, the inclusion of AEC reduces the gap between the lowest and highest quintiles in terms of TFPC, realigns the ranking among quintiles and yields a higher rate of TFP growth for the sample.

Table 9 shows the TFPC decomposition over time by quintile and overall. The rates of growth in this case exhibit a heterogeneous pattern although some regularities are observed.

[3] The interest rates used are: 2005 = 4.97%; 2006 = 5.45%; 2007 = 4.43%; 2008 = 4.92%; and 2009 = 4.80%.

For all five quintiles and for both TFPC1 and TFPC2, productivity growth is positive in all cases for 2006-2005 and 2009-2008 except for one case in the former, and negative for all cases for 2008-2007. The rest of the changes show a mixed pattern although quintiles III and V exhibit more periods with positive growth compared to quintiles I, II and IV. The year to year overall average changes reveal generally a U shaped tendency overtime for both TFPC1 and TFPC2. The growth rate for TFPC1 is for 2006-2005 at 0.989%, decreases to 0.751% for 2007-2006 then is -2.333% for 2008-2007 turning to the highest and positive for 2009-2008 at 1.328%. The corresponding figures for TFPC2 are 2.682%, 0.471%, -6.867% and 6.414%.

6. SUMMARY AND CONCLUDING REMARKS

The focus of this paper was to examine Total Factor Productivity Change (TFPC) for a sample of Chilean dairy operations located mainly in Southern Chile in the Los Lagos and Los Ríos Regions, which is the most important milk production area in the country. The study adds to the ongoing debate concerning the future viability of small farms and their possible contribution to poverty reduction and to overall economic development, particularly in poor and middle income countries. Beyond this controversy, it is safe to argue that, at least in the midterm, small farms will continue to be a significant player, especially in the poorer countries, and thus understanding the forces that account for productivity growth across farms differing in size is important.

This paper used an unbalanced panel data set to measure and to decompose TFPC for a sample of dairy farms located in Southern Chile. The period of analysis goes from 2005 to 2009 and the data includes a total of 417 farms and 1,186 observations. Farm size ranges from 18 to 1,404 cows with output ranging from 40,071 to 11,290,158 L.

A descriptive analysis of the data reveals an overall average cost of production per liter of milk equal to US $0.24 whereas the lowest average cost/L is US $0.189 for the smallest farm size quintile in 2006 and the highest is US $0.303 for the largest quintile in 2008. The average operational profit/L for the overall sample is US $0.058 ranging from US $0.028 for the largest quintile in 2009 to US $0.085 for the same group in 2007. The average operational profit/L for the smallest quintile for the 5 years is slightly lower at US $0.053 than the average for the largest quintile at US $0.057. The overall average returns to capital (including land), family labor and management for the sample is US $91,000 going from an average of US $12,000 for the smallest quintile in 2009 to a high of US $311,000 for the largest quintile in 2007.

A translog stochastic production frontier model is estimated and then used to perform a full TFPC decomposition based on Kumbhakar and Lovell (2000) and Coelli et al. (2003). The productivity components examined are: Technological Change (TC); Scale Efficiency Change (SEC); Technical Efficiency Change (TEC); and Allocative Efficiency Change (AEC). The econometric results reveal that the value of the function coefficient is very close across different size groups ranging from 0.924 to 0.974 indicating that this sample exhibits a nearly CRS technology, which is consistent with the descriptive analysis of average costs. Technical Efficiency (TE) scores are also very close across quintiles ranging from 83.7% for the smallest farm group to 94.1% for the largest with an overall mean of 90.2%.

We calculate two measures of TFPC: 1) TFPC1 which includes TEC, TC, and SEC; and 2) TFPC2 which, in addition to the components included in TFPC1, incorporates AEC. The average annual rate of growth for TFPC1 is 0.186% and the lowest average annual rate is exhibited by the smallest group (quintile I) at -1.795% while the highest is for quintile IV at 1.028%. By comparison, the inclusion of AEC in TFPC2 increases the average annual rate of growth in TFP to 0.628% while the lowest rate of growth is for quintile II at 0.193% and the highest is again for quintile IV at 1.003%.

A noteworthy implication of the relatively high TE levels measured and the low TEC is that productivity gains through management improvements are limited. By contrast, the measured rate of technological progress is rather low suggesting that additional investments in research could have a promising role in the promotion of productivity growth. The contributions of this research seem even more relevant in the current environment of growing market liberalization. Farmers in developing countries face increasing competition from their peers in other places including rich economies where the public sector provides relatively high levels of support to agricultural research, innovation and extension services.

The evidence derived from our investigation suggests that farm size does not play a significant role in the productivity of the dairy farms in the sample. However, the analysis does show a clear positive association between herd size and farm income. Moreover, aggregate country level data reveals a clear structural change in Chilean dairy production over the past 15 years toward fewer and larger farms. The implication of our results combined with the observed structural change is that a major driver of dairy farm growth is the search for higher returns to capital and management rather than lower costs of production.

As we look to the future, it is reasonable to expect that the Chilean agricultural sector exhibits good prospects given the country's advantageous natural resource base, political stability and rapidly evolving physical infrastructure. Therefore, we can envision the coexistence of a wide spectrum of farm sizes provided that other sources of income, perhaps from non-farm rural activities, are available for the small scale farmers that wish to supplement their dairy production income. Nevertheless, if the Chilean economy remains on a steady growth path, we can anticipate further structural change away from smaller farms in favor of larger operations as workers are drawn to more lucrative opportunities outside of agriculture. This can be particularly true in dairy farming where the option to mechanize various facets of the production process are readily available while larger farms, if they continue to generate healthy returns, would be in a position to absorb the smaller operations in order to further enhance profits.

7 ACKNOWLEDGMENTS.
This work was partially supported by the National Fund for Science and Technology (FONDECYT) under Grant 11110285.

Table 1. Structural Change in Chilean Dairy Farming: 1996-97 vs 2006-07

	Census Year		%
	1996-97	**2006-07**	**Change**
Panel-A			
Cows per Farm	**Total Number of Cows**		
1 to 99	362,947	181,011	-50.1
100 to 199	105,415	80,362	-23.8
200 and more	149,250	234,092	56.8
Overall	**617,612**	**495,465**	**-19.8**
Panel-B			
Cows per Farm	**Total Number of Farms**		
1 to 19	43,657	16,164	-63.0
20 to 49	3,107	1,717	-44.7
50 to 99	1,177	677	-42.5
100 to 149	510	353	-30.8
150 to 199	267	225	-15.7
200 to 299	250	294	17.6
300 to 499	147	212	44.2
500 and more	39	97	148.7
Total	**49,154**	**19,739**	**-59.8**

Source: Table prepared by authors from Agricultural Census Data for 1996-97 and 2006-07 obtained from INE (2010).

Table 2. Summary of the Structure of the TODOAGRO Panel Data: 2005-2009

Number of years	**5**	**4**	**3**	**2**	**1**	**Total**
Number of farms	**87**	**68**	**51**	**115**	**96**	**417**
Percentage of total farms	20.9%	16.3%	12.2%	27.6%	23.0%	
Cumulative percentage	20.9%	37.2%	49.4%	77.0%	100.0%	
Number of observations	**435**	**272**	**153**	**230**	**96**	**1,186**
Percentage of total observations	36.7%	22.9%	12.9%	19.4%	8.1%	
Cumulative percentage	36.7%	59.6%	72.5%	91.9%	100.0%	

Table 3. Yearly Averages for All Farms, and 20% Smallest and 20% Largest Farms According to Milk Production

	All Farms					20% Smallest Farms						20% Largest Farms						
	Years					Years						Years						
	2005	**2006**	**2007**	**2008**	**2009**	**2005**	**2006**	**2007**	**2008**	**2009**	**Avg.**	**2005**	**2006**	**2007**	**2008**	**2009**	**Avg.**	
Variables																		
Number of farms	167	282	256	244	237	30	64	57	40	47	48	39	53	51	46	48	47	
Production Function Variables																		**Overall Average**
Milk production (1,000 L)	1,731	1,476	1,563	1,648	1,658	377	321	347	335	319	331	3,536	3,398	3,650	3,841	4,018	3,687	**1,602**
Herd size (dairy cows)	276	237	251	261	277	83	71	76	78	76	75	512	488	517	518	573	522	**258**
Concentrate feed (Ton)	433	345	376	414	378	39	40	57	57	50	49	999	949	983	1,092	1,043	1,011	**385**
Forage Cost (1,000 $)	61	48	70	101	85	14	11	15	20	15	15	120	112	159	238	214	168	**73**
Labor Cost (1,000 $)	55	46	50	56	57	11	10	12	12	11	11	107	105	113	126	133	117	**52**
Veterinary expenses (1,000 $)	21	18	21	22	22	3	3	4	4	3	3	43	42	52	53	56	50	**21**
Other Costs (1,000 $)	75	60	66	80	76	17	15	17	20	16	17	164	138	152	188	187	165	**71**
Other Variables																		
Land (ha)	144	126	130	138	147	52	45	49	52	51	49	267	257	253	253	280	264	**136**
Concentrate feed (Kg/cow)	1,371	1,237	1,311	1,415	1,173	455	615	789	771	726	684	2,016	2,003	1,957	2,102	1,853	1,973	**1,296**
Milk production (L/cow)	5,406	5,380	5,480	5,615	5,167	3,566	4,182	4,374	4,195	4,087	4,134	6,480	6,601	6,676	7,028	6,573	6,650	**5,411**
Total Cost of Production ($/L)	0.209	0.198	0.265	0.282	0.242	0.207	0.193	0.267	0.261	0.229	0.231	0.220	0.212	0.271	0.305	0.258	0.255	**0.240**
Milk Price ($/L)	0.265	0.249	0.342	0.356	0.270	0.245	0.237	0.326	0.337	0.257	0.280	0.278	0.260	0.356	0.368	0.287	0.310	**0.298**
Operational Profit ($/L)	0.055	0.050	0.077	0.073	0.027	0.039	0.044	0.059	0.076	0.028	0.049	0.058	0.048	0.085	0.063	0.028	0.057	**0.057**
Operational Profit (1,000 $)	98	75	128	113	40	17	18	23	27	12	19	199	161	311	225	85	196	**91**

Table 4. Parameter Estimates for the Translog Production Frontier Model

Variable	Parameter	Std. Error	Variable	Parameter	Std. Error	Variable	Parameter	Std. Error
Frontier model								
Constant	0.126 ***[a]	*0.017*[b]	CO^2	-0.099	*0.084*	CF FC	0.027 ***	*0.009*
CO	0.396 ***	*0.019*	CF^2	0.022 ***	*0.002*	CF VE	0.053 ***	*0.008*
CF	0.178 ***	*0.008*	LB^2	0.061	*0.048*	CF OC	-0.017 *	*0.009*
LB	0.068 ***	*0.014*	FC^2	0.035	*0.025*	CF T	-0.003	*0.003*
FC	0.108 ***	*0.011*	VE^2	0.049 ***	*0.009*	LB FC	-0.003	*0.027*
VE	0.098 ***	*0.014*	OC^2	0.002	*0.015*	LB VE	-0.074 **	*0.029*
OC	0.098 ***	*0.014*	T^2	-0.005	*0.006*	LB OC	0.014	*0.027*
T	0.002	*0.007*	CO CF	-0.103 ***	*0.014*	LB T	0.015 *	*0.011*
ZD2	-0.018 *	*0.011*	CO LB	0.012	*0.045*	FC VE	-0.080 ***	*0.024*
ZD3	0.061 ***	*0.017*	CO FC	0.090 ***	*0.034*	FC OC	-0.066 **	*0.027*
ZD4	-0.029 **	*0.012*	CO VE	0.034	*0.037*	FC T	0.004	*0.008*
ZD5	-0.026	*0.019*	CO OC	0.098 **	*0.042*	VE OC	-0.003	*0.032*
DD	-0.089 ***	*0.019*	CO T	-0.051 ***	*0.014*	VE T	0.017 **	*0.009*
			CF LB	0.003	*0.013*	OC T	0.013	*0.011*
Inefficiency component								
Constant	-0.082	*0,164*						
T	-0.403 ***	*0,099*						
T^2	0.069 ***	*0,016*						
LD	-17.540 ***	*3,052*						
LD^2	22.506 ***	*3,909*						
Sigma-squared				0.257 ***	0.004			
Gamma				0.963 ***	0.007			
Function Coefficient				0.947				
Log Likelihood Function				618.5				

CO, Cows; CF, Concentrated feed; LB, Labor; FC, Forage cost; VE, Veterinary expenses; OC, Other cost: T, Time; ZD, Zone Dummy; DD, Drought Dummy; LD, Land size.

Table 5. Monotonicity by Input for the Translog Model

	Number of positive	Number of negative	Total observations
Cows	1,185	1	1,186
	99.9%	0.1%	100.0%
Concentrated feed	1,169	17	1,186
	98.6%	1.4%	100.0%
Labor	1,156	30	1,186
	97.5%	2.5%	100.0%
Forage cost	1,169	17	1,186
	98.6%	1.4%	100.0%
Veterinary expenses	1,133	53	1,186
	95.5%	4.5%	100.0%
Other costs	1,181	5	1,186
	99.6%	0.4%	100.0%

Table 6. Partial Elasticities of Production by Quintiles and Average for all Farms

	Quintiles					
	I	II	III	IV	V	
	0-20%	**20-40%**	**40-60%**	**60-80%**	**80-100%**	**Average**
Cows	0.416	0.379	0.382	0.383	0.399	0.392
Concentrated feed	0.132	0.173	0.190	0.193	0.201	0.178
Labor	0.077	0.069	0.060	0.067	0.072	0.069
Forage cost	0.122	0.115	0.102	0.108	0.097	0.109
Veterinary expenses	0.071	0.103	0.112	0.108	0.105	0.100
Other costs	0.106	0.096	0.097	0.096	0.100	0.099
Total (Function Coefficient)	**0.924**	**0.935**	**0.943**	**0.956**	**0.974**	**0.946**

Table 7. Technical Efficiency Scores by Quintiles and Overall

Groups		No. of Farms	Milk Equivalent (L)	Technical Efficiency Mean	Min.	Max.
0-20%	**I**	240	337,871	0.837	0.202	0.975
20-40%	**II**	239	790,117	0.888	0.681	0.969
40-60%	**III**	236	1,307,643	0.916	0.635	1.000
60-80%	**IV**	236	1,924,122	0.929	0.758	0.984
80-100%	**V**	235	3,693,010	0.941	0.663	0.974
Overall		**1,186**	**1,602,429**	**0.902**	**0.202**	**1.000**

Table 8. Total Factor Productivity Change (TFPC) Decomposition by Quintile

			--%--	--%--	--%--	--%--	--%--	--%--
Groups		**No. of Farms**	**TEC**[a]	**TC**	**SEC**	**TFPC1**	**AEC**	**TFPC2**
0-20%	**I**	240	-1.747	-0.645	0.597	-1.795	2.053	0.258
20-40%	**II**	239	0.650	0.116	-0.154	0.612	-0.419	0.193
40-60%	**III**	236	-0.528	0.477	-0.080	-0.131	1.020	0.889
60-80%	**IV**	236	0.792	0.399	-0.163	1.028	-0.025	1.003
80-100%	**V**	235	0.224	0.785	-0.189	0.820	-0.175	0.645
Overall		**1,186**	**-0.066**	**0.275**	**-0.022**	**0.186**	**0.442**	**0.628**

[a] TEC, technical efficiency change; TC, technological change; SEC, scale efficiency change; TFPC1, total factor productivity change according to Nishimizu and Page (1982) equal to TEC+TC+SEC; AEC, allocative efficiency change; TFPC2, total factor productivity change according to Kumbhakar and Lovell (2000) and Coelli et al. (2003) equal to TEC+TC+SEC+AEC.

Table 9. Total Factor Productivity Change (TFPC) Decomposition by Year

		--%--	--%--	--%--	--%--	--%--	--%--
Group/Year	**No. of Farms**	**TEC[a]**	**TC**	**SEC**	**TFPC1**	**AEC**	**TFPC2**
0-20% I							
2006-2005	21	-8.029	-0.932	1.525	-7.436	9.718	2.282
2007-2006	36	1.123	-0.236	-1.120	-0.233	0.188	-0.045
2008-2007	35	-2.415	-0.200	-0.239	-2.854	-3.001	-5.855
2009-2008	33	-0.174	-1.382	2.769	1.212	4.571	5.783
20-40% II							
2006-2005	21	6.033	0.238	-0.502	5.769	1.162	6.931
2007-2006	40	1.129	0.191	-0.724	0.595	-2.897	-2.302
2008-2007	37	-3.481	0.175	-0.522	-3.829	-5.799	-9.628
2009-2008	37	1.209	-0.095	1.029	2.143	6.742	8.885
40-60% III							
2006-2005	35	1.750	0.845	-0.265	2.330	-0.748	1.581
2007-2006	46	-0.429	0.578	-0.072	0.077	3.939	4.017
2008-2007	38	-3.674	0.382	-0.632	-3.923	-4.345	-8.268
2009-2008	40	0.355	0.130	0.595	1.080	4.307	5.386
60-80% IV							
2006-2005	40	0.884	0.787	-0.193	1.477	1.601	3.078
2007-2006	48	1.382	0.523	-0.411	1.494	-2.279	-0.785
2008-2007	33	-1.059	0.599	-0.466	-0.926	-4.407	-5.334
2009-2008	41	1.500	-0.284	0.401	1.617	4.557	6.174
80-100% V							
2006-2005	44	0.501	1.024	-0.308	1.217	0.143	1.360
2007-2006	44	1.120	0.773	-0.300	1.594	-0.514	1.080
2008-2007	41	-0.889	0.890	-0.196	-0.195	-4.982	-5.176
2009-2008	36	0.058	0.388	0.097	0.543	5.324	5.868
All Farms							
2006-2005	161	0.477	0.568	-0.056	0.989	1.693	2.682
2007-2006	214	0.848	0.397	-0.493	0.751	-0.280	0.471
2008-2007	184	-2.306	0.382	-0.408	-2.333	-4.535	-6.867
2009-2008	187	0.624	-0.223	0.926	1.328	5.086	6.414
Overall Avg	**746**	**-0.066**	**0.275**	**-0.022**	**0.186**	**0.442**	**0.628**

[a] TEC, technical efficiency change; TC, technological change; SEC, scale efficiency change; TFPC1, total factor productivity change according to Nishimizu and Page (1982) equal to TEC+TC+SEC; AEC, allocative efficiency change; TFPC2, total factor productivity change according to Kumbhakar and Lovell (2000) and Coelli et al. (2003) equal to TEC+TC+SEC+AEC.

Figure 1. Geographical Location of the Dairy Farms in the Dataset

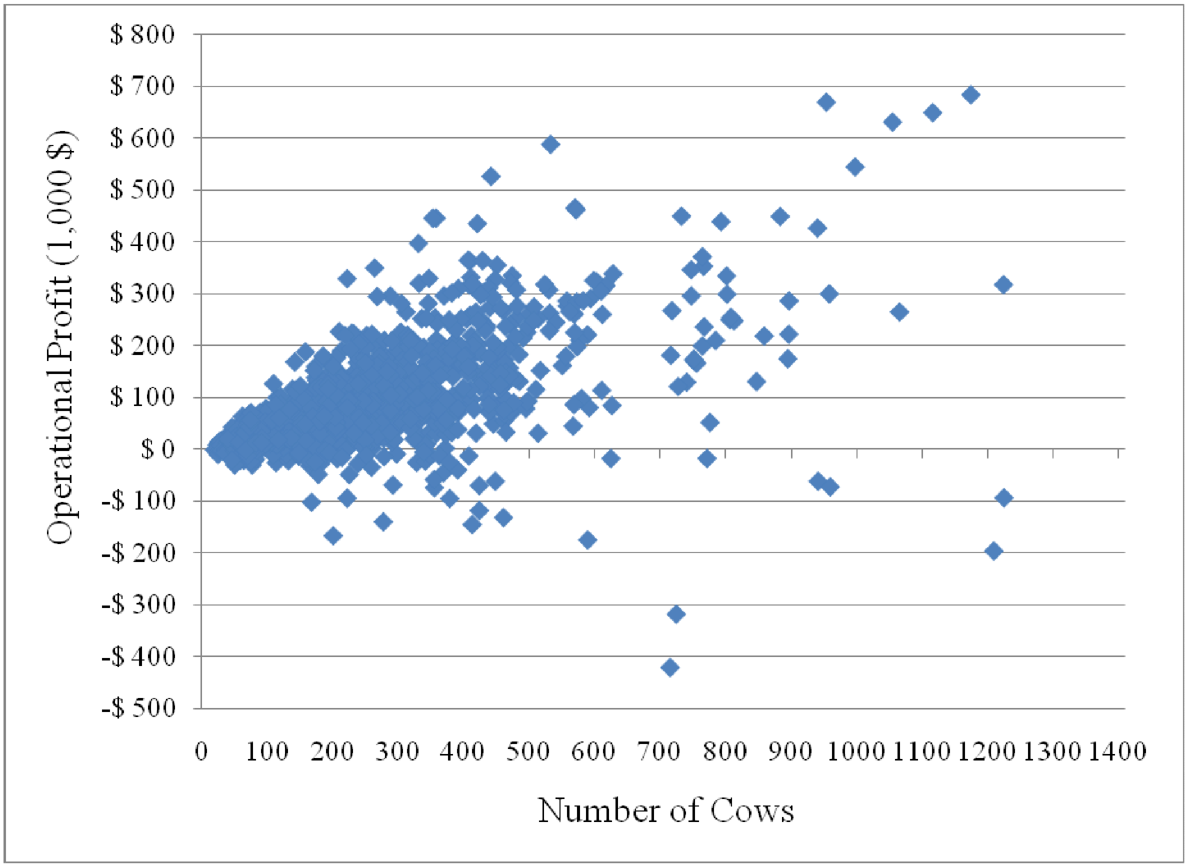

Figure 2. Relationship between Operational Profits (1,000 $) and Number of Cows

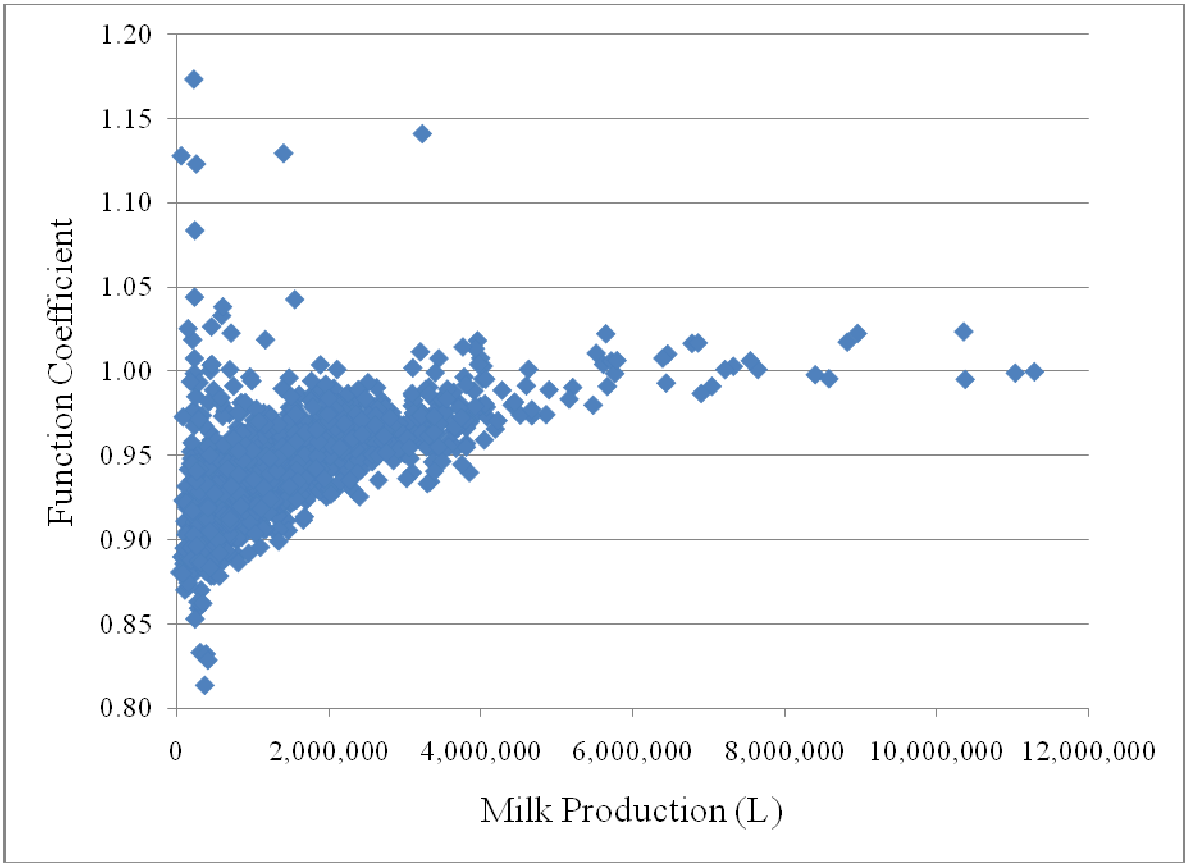

Figure 3. Relationship between Function Coefficient Values and Milk Production

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