African Journal of Agricultural Research Vol. 7(13), pp. 2063-2071, 5 April, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR11.1230
ISSN 1991-637X © 2012 Academic Journals

Full Length Research Paper

Dairy productivity in the Waikato region of New Zealand, 1994-2007

Michael P. Cameron[1]* and Kendon Bell[2]

[1]Department of Economics, University of Waikato, Private Bag 3105, Hamilton, New Zealand.
[2]Department of Economics, University of Waikato, Private Bag 3105, Hamilton, New Zealand.

Accepted 11January, 2012

The dairy industry is a major contributor to both the New Zealand economy as a whole and to the Waikato regional economy in particular. The industry is experiencing a period of considerable change with increase in dairy conversion, increased intensification, and increasing use of nitrogen fertilizers, each of which has an associated environmental cost. In this paper, the productivity performance of the mature dairy industry in the Waikato region is investigated using panel data at the sub-regional level from 1994 to 2007. In general we show that, under a range of specifications, productivity growth independent of increasing land use and herd numbers has been significantly below the four percent industry target. This suggests that, if the four percent goal were to be met in the absence of substantial technological progress, further increases in fertilizer use, land use, and/or farming intensity would be required.

Key words: Productivity, dairy industry, Waikato, New Zealand.

INTRODUCTION

The dairy industry is a major contributor to both the New Zealand economy as a whole and to the Waikato regional economy in particular. In the September, 2004 year dairy farming directly provided 7.4% of Waikato gross regional product (in value-added terms) and 6.6% of full-time equivalent employment (Hughes et al., 2005). Dairy farming and dairy processing combined contributed 10.1% of gross regional product and 8.0% of employment. The dairy industry provides the highest industry contribution to gross regional product, and is second only to retail trade in terms of employment. The dairy industry is experiencing a period of considerable change. Historically, high international dairy commodity prices, coupled with lower returns on sheep, beef and forestry have driven increases in land use conversion to dairy farming and increased intensification of farming on existing dairy farms (MacLeod and Moller, 2006; Cameron et al., 2010). Increasing use of nitrogen fertilizers has increased pasture yields, but at an environmental cost of nitrate leaching and increased emissions of nitrous oxide (Clark et al., 2007; Parliamentary Commissioner for the Environment (PCE), 2004). Increasing incidence and intensity of dairy farming also have considerable implications in terms of New Zealand's liabilities under the Kyoto protocol (New Zealand Climate Change Office, 2004). Furthermore, New Zealand's largest dairy producer, Fonterra, has been targeting at least 3% productivity growth across their entire value chain since 2002 (Fonterra, 2002), while the dairy industry itself had until recently a target of 4% productivity growth (Dairy Insight, 2004). The revised dairy industry strategy in 2009 reduced the emphasis on high productivity growth but noted that productivity growth was important if the industry was to remain competitive in facing increasing global competition and rising input costs (DairyNZ, 2009).

In a mature dairy region such as the Waikato region of New Zealand, where the most suitable land is already employed in dairy farming, achieving productivity growth of 4% will likely be driven by: (i) increasing stocking rates (that is, increasing the number of cows at a faster rate than the growth in land use for dairy production); (ii)

*Corresponding author. E-mail: mcam@waikato.ac.nz. Tel: +64 7 858 5082. Fax: +64 7 838 4331.

increasing use of land for dairy production; (iii) changes in farm management practices including increased intensity of fertilizer use to improve pasture yields; and/or (iv) technological or other improvements. Points (i) and (ii) will only be effective if there are increasing marginal returns to dairy stock and land respectively.

There have been several investigations on the productivity growth performance of New Zealand agriculture, but very few have focused specifically on estimating productivity growth in the dairy industry. Dexcel (2007) used farm-level data and estimated annual productivity growth in the New Zealand dairy industry at 1.4% over a 10 year period to 2006, although, the non-representative nature of the farm data used suggests that this rate of productivity growth may be an overestimate as the self-selected sample will likely include more highly motivated farms with above average productivity. Mullen et al. (2006) estimated annual multifactor productivity growth in New Zealand agriculture at 2.2% over the period from 1984 to 2001 using a growth accounting approach. Forbes and Johnson (2001) estimated annual total factor productivity growth in agriculture at 3.5% over the period from 1985 to 1998 and an annual total input productivity growth at 1.5% over the period from 1972 to 1998 using an index number approach, while Coelli and Rao (2003) estimated an annual productivity growth in agriculture at just 0.4% over the period from 1980 to 2000 using a Malmquist Index approach. The different approaches to estimating growth in total factor productivity are described in detail by Coelli et al. (2005).

In this paper the productivity performance of the dairy industry in the Waikato region is investigated, using panel data on outputs and inputs at the Territorial Local Authority (TLA) level from 1994 to 2007. In particular, this paper determines whether 4% productivity growth can be achieved without increased farming intensity (that is, increasing use of inputs (for example, fertilizer and irrigation) to produce more food from the same area of land (Johnston et al., 2000) or increasing land use, by estimating total input productivity growth while accounting for the number of dairy stock and the land applied to dairy farming. Sub-regional fixed effects are used to control unobserved factors such as differences in land quality between different TLAs. A further source of novelty for this paper is that the effects of changing weather patterns on production are controlled by including aggregate climate data; a key input into pasture growth and hence, dairy production.

In all, we show that under a range of specifications, total input productivity growth independent of climate effects, increasing land use and herd numbers is around 1.2 to 1.5% per year which is significantly below the original 4% dairy industry target and the 3% target of Fonterra. Further, we show that productivity gains are unlikely to result from either increasing stocking rates or increasing conversion of land to dairy farming due to the estimated diminishing marginal product of both dairy cows and land. This suggests that, if a 3 or 4% goal was to be met in the absence of significant technological progress, further increases in fertilizer and other input use would be required, with consequent environmental costs. Higher productivity growth can, therefore, probably be only sustainably achieved through an increased pace of technological improvement and innovation, requiring substantial increases in investment in agricultural research and development.

Table 1 presents data on the increase in milk solids production, increase in dairy stock numbers, and increase in land used for dairy production for the Waikato region as a whole and for selected Territorial Local Authorities (TLAs) in the region over the period of 1994 to 2007. Production of milk solids has grown by over 39% over the period at an average annualized rate of 2.6%. The data in Table 1 demonstrate three important trends. First, dairy stock numbers are growing faster than land use (18.5% growth in dairy stock numbers over the 1994 to 2007 period as compared to 9.3% growth in land area devoted to dairy production), which indicates increasing stocking rates and increasing intensification of farming. This increase is apparent across all TLAs in the region, including those in which total production is declining. Secondly, much of the additional production (2.6% annualized growth) can probably be explained by the increase in dairy stock numbers (1.3% annualized growth) and land use (0.7% annualized growth). This suggests immediately that total productivity growth may well be lower than three percent on the average across the region and finally, there are distinct differences in the growth of production and inputs between TLAs. The 'mature' dairying TLAs (such as Matamata-Piako, Waipa, and Waikato districts), which provide the majority of dairy production in the region have experienced average or below average growth in production. 'Newer' dairying areas such as Taupo district have experienced significant growth in production, driven mainly by a rapid conversion of land to dairy farming.

These trends raise two important research questions, which will be addressed in this paper: (i) what is the total productivity growth performance of the Waikato region and how does it compare with goals of three and four percent growth after accounting for changes in dairy stock numbers and land use? and (ii) what does this imply about what can be achieved in terms of total productivity growth, without intensifying land use or fertilizer use? Most estimates of total productivity growth consider total factor productivity (TFP); that is, the ratio of net output (value added or Gross Domestic Product) to the combined inputs of labour and capital (which can be broadly defined). In this paper we estimated total input productivity (TIP), an alternative measure to TFP, which is the ratio of gross output to all inputs, including materials, labour and capital. TIP was preferred as a measure for this study because it is consistent with the concept of productivity contained in previous dairy industry

Table 1. Changes in Waikato dairy production, 1994-2007.

TLA	Growth in dairy stock numbers		Growth in effective land area		Growth in milk solids production		Proportion of total production in 2007 (%)
	Total 1994-2007 (%)	Annualized (%)	Total 1994-2007 (%)	Annualized (%)	Total 1994-2007 (%)	Annualized (%)	
Franklin	-18.6	-1.6	-21.2	-1.8	-3.6	-0.3	4.6
Waikato	13.3	1.0	2.5	0.2	35.4	2.4	15.3
Hamilton city	26.5	1.8	26.2	1.8	54.1	3.4	0.2
Waipa	21.3	1.5	7.1	0.5	39.2	2.6	13.8
Otorohanga	32.0	2.2	24.3	1.7	48.3	3.1	9.0
Thames-Coromandel	5.0	0.4	-4.2	-0.3	12.9	0.9	1.5
Hauraki	10.4	0.8	3.6	0.3	27.3	1.9	8.3
Matamata-Piako	-2.3	-0.2	-11.1	-0.9	16.3	1.2	21.8
South Waikato	25.1	1.7	17.5	1.2	47.1	3.0	9.2
Taupo	245.2	10.0	212.0	9.1	338.9	12.1	5.5
Rotorua	52.7	3.3	35.1	2.3	80.7	4.7	9.5
Waitomo	169.0	7.9	125.7	6.5	202.6	8.9	1.4
Waikato region	18.5	1.3	9.3	0.7	39.1	2.6	100.0

productivity targets (Dairy Insight, 2004), and in some previous studies of dairy industry productivity (Dexcel, 2007). This allows for easy comparison between estimated productivity in this paper and the published productivity targets.

MATERIALS AND METHODS

The data used in this analysis were collected primarily from Livestock Improvement Corporation Dairy Statistics publications (LIC, 1993 to 2007, annual). These data include dairy production, dairy cow numbers, and effective land area devoted to dairying, and the number of dairy farms for each of the twelve TLAs entirely or partly contained in the Waikato region. A detailed description of these data is presented by Cameron and Bell (2008). The years included in this analysis (1993 to 2007) are those that afforded no discontinuities or issues relating to consistency in data collection or interpretation, that is, such that a balanced panel with no missing data could be developed. Additionally, spatially explicit data on rainfall and temperature were obtained from the National Institute of Water and Atmospheric Research (NIWA). For the purposes of this analysis, these data were aggregated from grid cells of approximately 5 km to obtain the mean annual rainfall and mean temperature in each TLA in each year.

There are currently no comprehensive disaggregated and spatially-explicit data sets on either capital or labour employed in the dairy farming sector in New Zealand. DairyNZ collects data from a national sample of farms as part of the DairyBase survey, but this data is highly aggregated (DairyBase, 2006). In this analysis we constructed a time series of labour input using data on the average full-time equivalent labour input for all New Zealand farms from the DairyBase database, combined with data on the number of dairy farm units from Livestock Improvement Corporation Dairy Statistics publications. This means that, we are effectively using the number of dairy farm units as a proxy for labour input since the average full-time labour input is invariant across TLAs. Alternatively, we could have created a similar time series for capital input, but the regression results and productivity estimates would remain the same.

All specifications were estimated from a total of 168 observations, being a balanced panel of fourteen years of data (1994 to 2007) from the twelve Waikato TLAs. Estimating separate equations for each TLA was initially considered; however, a dynamic fixed effect panel approach was adopted as a more suitable specification when compared to individual TLA-level models due to the short time period used to estimate the model. The implicit assumption in this specification is that the marginal effects (elasticities) of the included independent variables are invariant across the TLAs. In estimating total input productivity growth, the production function in Equation (1) was initially specified:

$$\ln (Y_{it}) = \beta_1 \ln (C_{it}) + \beta_2 \ln (N_{it}) + \beta_3 \ln (F_{it} {*} L_t) + f(R_{it}, T_{it}) + Z_t + A_i + \varepsilon_{it} \quad (1)$$

Where;

Y_{it} is the total dairy output in district i at time t; C_{it} is the total dairy stock units in district i at time t, as measured by "all cows lactating in that season" (LIC, 2007: 6);
N_{it} is the land area devoted to dairy production in district I at time t in hectares;

F_{it} is the number of dairy farms operating in district *i* at time *t*;
L_t is the average FTEs per dairy farm for New Zealand at time *t*;
R_{it} is the annual rainfall in district *i* at time *t* in mm/year;
T_{it} is the annual average temperature in district *i* at time *t* in degrees Celsius;
$f(R_{it},T_{it})$ is a logarithmic function of R_{it} and T_{it} to be specified;
Z_t is a year specific intercept;
A_i is an unobserved time-invariant district specific effect;
ε_{it} is a possibly autoregressive error term;
β are parameters to be estimated;
i have a range of 1 to 12, with each number representing one of the Waikato TLAs; and
t have a range of 1994 to 2007.

Preliminary examination of these data suggested the errors arising from a static representation of this model were auto-correlated, with a calculated Durbin-Watson statistic of 1.35. A Durbin-Watson statistic substantially below 2 indicates auto-correlation of the error term. When errors are auto-correlated, the estimates of the time fixed effects arising from Ordinary Least Squares regression (OLS) are consistent but in general, the standard errors are not. The use of 'White diagonal' standard errors allows estimation of standard errors that are robust to heteroskedasticity through time as well as, across districts; however, these standard errors are not robust to auto-correlation of the error term. To deal with this, a dynamic form of the production function was instead adopted. In this specification, the error term is assumed to follow the AR (1) process:

$$\varepsilon_{it} = \rho\varepsilon_{i,t-1} + \upsilon_{it} \quad (2)$$

With $\rho \neq 0$. Multiplying Equation (1), for period *t*-1, by ρ, adding the left hand side, and subtracting the right hand side from Equation (1) (for period *t*) yields a dynamic representation of the production function:

$$\ln(Y_{it}) = \beta_1\ln(C_{it}) - \rho\beta_1\ln(C_{i,t-1}) + \beta_2\ln(N_{it}) - \rho\beta_2\ln(N_{i,t-1}) + \beta_3\ln(F_{it}{}^*L_t) - \rho\beta_3\ln(F_{i,t-1}{}^*L_{t-1}) + f(R_{it},T_{it}) - \rho f(R_{i,t-1},T_{i,t}-1) + \rho\ln(Y_{i,t-1})\, Zt^* + (1-\rho)A_i + \upsilon_{it} \quad (3)$$

Where:

$$Z_t^* = Z_t - \rho Z_{t-1}.$$

The resulting error term, υ_{it}, is serially uncorrelated if ε_{it} follows an AR (1) process. In this paper, we used OLS to estimate the coefficients in this specification. A General Method of Moments (GMM) estimation using the Arellano-Bond estimator (Arellano and Bond, 1991) was trialled and produced an average TIP growth estimate slightly lower than that reported in this paper, with qualitatively similar levels of significance of all coefficients and fixed effects. However, standard panel GMM estimators are designed for 'large N' datasets (Bond, 2002) and are subject to potentially large finite-sample biases in 'small N' datasets such as the dataset here. Thus we report the results obtained from a least squares estimator for the dynamic panel model. This method is superior to a simple growth accounting approach in two respects. First, it allows an estimation of TIP growth year to year, rather than simply an implied average growth rate over the period. The panel structure to our data allows this[1]. Secondly, this method places fewer restrictions on the process of the error term. Restricting $\rho = 1$ in Equation (3) and replacing the time fixed effects with a constant term yields a specification equivalent to simple growth accounting.

The TIP growth from year *t* to year *t + 1* is estimated as:

[1]When average TIP growth is estimated using a growth accounting approach, average TIP growth is slightly lower than that reported in this paper.

$$g_t = [\exp(Z_{t+1}) - \exp(Z_t)]/\exp(Z_t) \quad (4)$$

The dynamic representation of the production function means that the value of one single value of Z_t must be inferred in order to calculate all values of Z_t. Excel's Solver tool is used to find all values of Z_t, subject to the additional restriction that $\exp(Z_{1993})$ lies on the OLS regression line between *t* and $\exp(Z_t)$. Average TIP growth over the period is estimated by the average percentage growth in exp (Z_t) over time. We estimated this average by regressing Z_t against *t*, following Mullen et al. (2006). Separate models were estimated using three different measures of production: (i) total kilograms of milk solids; (ii) milk protein; and (iii) milk fat. All estimations produced qualitatively similar results and as such, only the models using milk solids as the measure of production are presented in this paper. All findings discussed in this paper for the milk solids estimation similarly extend to the models of the other two production measures.

The optimal functional form of the regression equation in relation to the climate variables, rainfall and temperature [$f(R,T)$] was difficult to establish. Nonlinear effects in the logs of these variables were expected. That is, high levels of both rainfall and temperature could be expected to yield lower production than the average along with low levels of rainfall and temperature, with some middle point being the optimal climatic conditions. Further, interactions between temperature and rainfall were expected. As such quadratics in the logs of these variables, along with an interaction term was trialled to model the climate effects. The statistical package used to perform the estimations was EViews version 6.

Some obvious inputs into dairy production are notably omitted from the aforesaid model and the observed variation in TIP on a yearly basis is likely to be partially driven by these omitted variables. This is due to the fact that the marginal effects of omitted variables will be captured within the time fixed effects, to the extent that the time fixed effects explain the variation in the omitted variable when controlling for the other included variables, potentially resulting in a biased estimate of TIP growth. Firstly, fertilizer is an important input into pasture growth and therefore, should be included in the model. However, data on aggregate fertilizer use is not readily available at the sub-regional level. Irrigation is another important input into pasture growth for which data are not available at the sub-regional level. The use of supplementary feeds, such as maize silage is another important input, particularly, in times of climatic shocks. Secondly, as noted earlier, capital is not able to be included because of data limitations.

The consequence of omitting these inputs on estimated TIP growth in the dairy industry depends on the extent to which the omitted inputs are explained by variation in the time fixed effects when controlling for the other included variables. Intuitively, an upward bias on average productivity growth could result if the omitted inputs have grown over time, over and above what could be expected from the observed overall growth in dairying. Clearly, the growth in dairy inputs is closely related to scale growth, which is captured by changes in stock numbers and effective hectares, suggesting the bias on the time fixed effects resulting from the exclusion of other inputs may be small.

Given these omissions, provided the average growth in use of inputs omitted from the specifications has been greater than the overall growth in dairying, then estimated total input productivity growth will be biased upwards in our estimations. MacLeod and Moller (2006) suggested that, for New Zealand as a whole, there has been substantial growth in fertilizer use, particularly, since 1990, as well as substantial increases in irrigation and the use of supplementary feed. Greater intensity of dairying also implies growth in capital and labour inputs (Cameron et al., 2010). Given these conditions it appears likely that an upward bias in estimated TIP growth will result. The results of the estimations of total input productivity presented in this paper should therefore be interpreted with a potential upward bias in mind.

Table 2. Regression results.

Dependent variable: ln (milk solids)	**Regression**			
Regressor	**1**	**2**	**3**	**4**
ln (Total number of dairy stock)	0.939*** (0.030)	0.764*** (0.059)	0.764*** (0.060)	0.764*** (0.060)
ln(Total effective hectares)		0.231*** (0.079)	0.238** (0.098)	0.222** (0.102)
ln (Average temperature (°C))				-2.622 (1.645)
ln (Average rainfall (mm/year))				-0.769 (0.551)
ln (rainfall)*ln(temperature)				0.305 (0.212)
ln (Average full-time employees (NZ) * number of farms)			-0.011 (0.08)	0.00004 (0.07)
ρ (Equation 3)	0.472*** (0.082)	0.424*** (0.074)	0.421*** (0.075)	0.408*** (0.074)
TLA fixed effects?	Yes	Yes	Yes	Yes
Period fixed effects?	Yes	Yes	Yes	Yes
Summary statistics				
$\bar{R}^2$	0.99961	0.99963	0.99963	0.99963
Test for redundant TLA fixed effects – likelihood ratio	p=0.0003	p=0.0000	p=0.0000	p=0.0043
Test for redundant period fixed effects – likelihood ratio	p=0.0000	p=0.0000	P=0.0000	p=0.0000
Implied average annual growth in total productivity	1.27%	1.39%	1.45%	1.47%

*** = significant at 1%, ** = significant at 5%, * = significant at 10%. White diagonal standard errors are presented below estimates, following Mullen et al. (2006), growth rates are determined by regressing the log of estimated total productivity on a constant and a time trend over the observation period.

RESULTS AND DISCUSSION

The estimation of the model shows, as expected, that the main determinant of the level of milk production in a district is the number of cows[2]. In comparison, other variables provided very little additional explanatory power. A number of selected specifications are presented in Table 2 and all selected specifications are estimated using the style of Equation (3). The preferred specification is regression (4), which includes log of dairy stock numbers, log of land area, log of estimated labour, the logs of the climate variables and the interaction between the logs of the climate variables, but no non-linearities in the logs of the climate variables. While the climate variables are calculated to be insignificant at the conventional levels, this specification best captures the interaction between temperature and rainfall. 'White Diagonal' heteroskedasticity-robust standard errors are presented in parentheses. These standard errors are consistent with heteroskedasticity through time as well as, across cross-section. The coefficients are estimated by OLS. However, given that we are estimating the dynamic representation of the production function (Equation 3), the coefficients are estimated using an iterative procedure provided by Eviews rather than the standard OLS formula.

As shown in Table 2, the coefficient on the log of total dairy stock numbers is approximately 0.76. This may be interpreted as the elasticity of production, that is, if dairy stock numbers increase by 10%, total milk solids production could be expected to increase by around 7.6% holding other variables constant. This demonstrates decreasing marginal returns to the number of cows. This is not an unexpected finding and is consistent with economic theory – in this case additional cows on a fixed amount of land and with a fixed amount of other resources would lead to additional production, but at a decreasing rate as the cows 'compete' for other productive resources.

The coefficient on the log of total effective area is approximately 0.22. Again, this is an elasticity of production. If total effective area were to increase by 10%, production would be expected to increase by 2.2% holding other variables constant. The size of a farm should affect the production of that farm positively, even when holding the herd size and other variables constant, as the cows would be better fed thereby, producing more milk. Two significant recent trends are apparent in land use on dairy farms. First is the increasing use of fertilizer and pesticides that has changed the pasture rotation on dairy farms, increasing the carrying capacity and the productivity of existing land (MacLeod and Moller, 2006). In contrast, the most productive land in the Waikato region is already applied to dairy farming, so additional land units are necessarily less productive than existing units reducing average productivity. Furthermore, if the stocking rates on existing land are close to optimal in terms of productivity, additional cows will require additional farmland in order for production to remain optimal, so that the net effect of land area over and above

[2]An R^2 of 0.9977 is obtained by running a simple regression of the log of production against the log of dairy stock numbers, with no fixed effects or dynamics.

the effect of additional cows, is likely to be small[3]. The effect of area suggested by the regression estimations in Table 2 is positive and significant but small relative to the effect of increasing cows, suggesting that a modest increase in production arises from additional land applied to dairy production, holding other variables constant. As the sum of the coefficients on effective area and cows is close to one, the model suggests there is a near constant return to scale in dairying, when considering just land area and cows as inputs.

The coefficient on the log of the number of dairy farms multiplied by either the average labour is interpreted as the marginal elasticity of adding more farms. The importance of the inclusion of labour or plant and machinery is the explanation of a portion of the unobserved time fixed effects used to estimate TIP growth. However, the inclusion of labour only increased estimated TIP growth from 1.39 to 1.45%. It should also be noted that this increase is inconsistent with our contention that the exclusion of labour caused an upward bias in estimated productivity growth. While the climate variables are found to be insignificant at the conventional levels of significance, they are 'close' to being significant and, because of the limited sample size, we also interpret the coefficients. It should also be noted that in a specification excluding the effective hectares variable, the specification of the climate variables is significant. The variables must be interpreted together as they interact. The elasticity of production with respect to temperature for the minimum, average (weighted by the level of production in each TLA in 2007) and maximum levels of rainfall are estimated as:

$$\frac{\partial \ln(Y)}{\partial \ln(T)}(R)\bigg|_{R=\{R_{min},\bar{R},R_{max}\}} = \{-0.50, -0.40, -0.25\}$$

Based on these calculations, the elasticity with respect to temperature is negative and inelastic for all levels of rainfall. If average annual temperature increases by 1% and rainfall is at its minimum over the study period, production could be expected to decrease by 0.50% and if rainfall is at its average, production could be expected to decrease by 0.40% and if rainfall is at its maximum over the study period, production could be expected to decrease by 0.25%. These figures imply that higher temperatures have an adverse effect on milk production. The figures support theoretical expectations of the interaction between rainfall and temperature in that higher temperatures have a far less severe impact on milk production in wetter years as compared with drier years. However, due caution should be exercised in extending these findings to temperatures outside the relevant range of average annual temperatures (between 10 and 15℃). Also, presumably due to the relatively small sample, the coefficients on the climate variables are likely to be somewhat sensitive to the regression specification.

The elasticity of production with respect to rainfall for the minimum, average (weighted by the level of production in each TLA in 2007) and maximum levels of temperature are estimated as:

$$\frac{\partial \ln(Y)}{\partial \ln(R)}(T)\bigg|_{T=\{T_{min},\bar{T},T_{max}\}} = \{-0.06, 0.03, 0.07\}$$

Based on these calculations, the elasticity of production with respect to rainfall is negative for low temperatures and positive for high temperatures. This means that if rainfall increases by 1% and temperature is at its minimum over the study period, then production could be expected to decrease by 0.06%, if temperature is at its average, production could be expected to increase by 0.03% and if temperature is at its maximum over the study period, production could be expected to increase by 0.07%. In other words, additional rainfall increases production for higher temperatures, while additional rainfall decreases production at lower temperatures. Interpreting both climate variables together by quadrant, cool and dry conditions are best for production, while cool and wet and hot and dry conditions are worst for production. An alternative specification was trialled in which quadratics in the logs of the climate variable were included. The coefficients on these quadratic terms were found to be jointly insignificant, suggesting the interaction term is enough to fully describe the non-linearity of the temperature and rainfall effects, and quadratic terms are unnecessary.

As the level of stock numbers explains 99.96% of the variation in the log of production in a fixed effects model (Regression 1 in Table 2), this raises the important question: Do other variables have an economically significant effect? Table 3 presents the 2008 predictions for Matamata-Piako district for the sample maximum and minimum value of each variable while holding other variables constant at their mean. This showed the predicted effect of a change from the lowest to the highest value of a variable, or the largest conceivable change in the variable. Table 3 uses regression (4) to investigate the substantiveness of the effects of each variable. We acknowledge that though the 2008 variables are, in reality, known, there was still the need to present the hypothetical predictions to demonstrate the concreteness of the effects.

Using Table 3, the substantiveness of the effects of each variable can be judged. Clearly, stock levels and effective hectares have concrete effects that are consistent with their calculated elasticities. The table also suggests temperature is a reasonably important variable with the percentage change in production around a third

[3] An interaction term between land area and the number of dairy cows proved to be insignificant in the regressions.

Table 3. Potential effects on total dairy production of changes in independent variables.

Independent variable	Predicted value of production for minimum of variable (kg 000s)	Predicted value of production for maximum of variable (kg 000s)	Percentage change in production (%)	Percentage change in independent variable (%)
Stock numbers	96039	106293	10.7	14.2
Effective hectares	100606	103284	2.7	12.6
Temperature	104205	98987	-5.0	12.0
Rainfall	100941	102550	1.6	52.0
Number of farms*FTEs	101591	101593	0.0	78.3

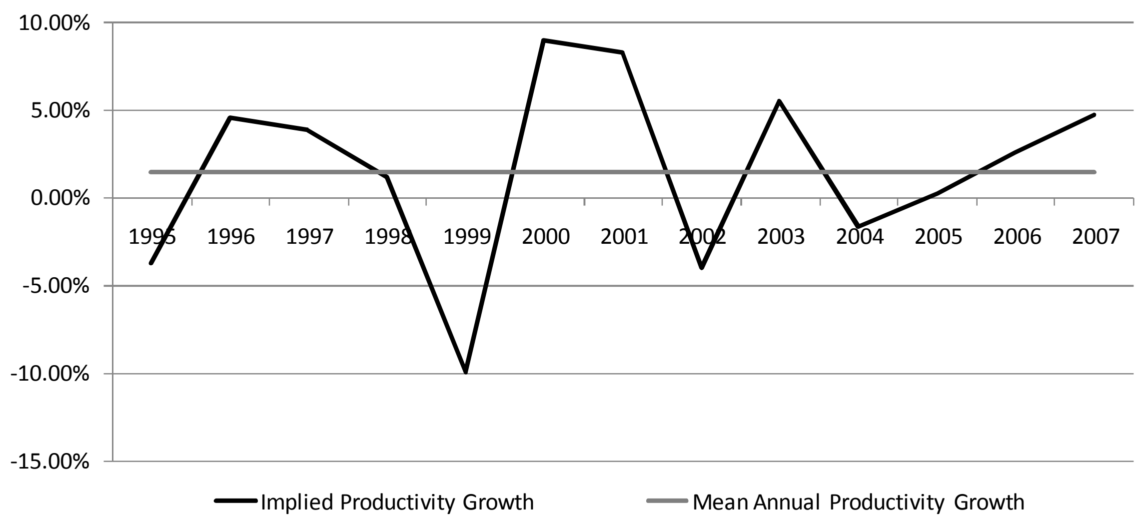

Figure 1. Annual TIP growth in the Waikato dairy industry 1994-2007.

of the percentage change in temperature in absolute terms. Rainfall has a small effect relative to its range, while the labour variable causes a negligible change in production.

Total input productivity growth in the Waikato dairy industry, 1994-2007

As noted earlier in Table 2, the TIP growth implied by the models is approximately 1.2 to 1.5% per year. Average annual growth in TIP is highest in Regression (4), at 1.47%. Comparing Regression (1) and (2), the inclusion of land has a small positive effect on estimated average annual growth in TIP. Likewise, the inclusion of labour further increases average annual growth in TIP to 1.45% (Regression 3). The further inclusion of climate variables slightly increased the average annual growth in TIP to 1.47% (Regression 4). The omitted variable biases noted earlier in the paper suggested that this estimated TIP growth is likely to be biased upwards, such that it can be concluded that estimated annual growth in TIP is significantly lower than the 4% target of the dairy industry, and the three percent target of Fonterra ($p<0.0001$). Furthermore, these estimates are consistent with the 1.4% over the ten-year period to 2006 estimated by Dexcel (2007), and the long-run TIP growth over the period 1972 to 1998 of 1.5% estimated by Forbes and Johnson (2001). As the Waikato is largely an established dairying region, the productivity growth estimated in this paper probably represents the TIP growth that is achievable in the dairy farming industry in a mature dairying region, without further intensifying input use and without significant technological changes that boost milk production.

The average annual rate of TIP growth masks significant variation between years. This variation is demonstrated by the estimated annual and mean annual TIP growth rates shown in Figure 1, which were derived from the time fixed effects estimated in Regression (4). The greatest trough in annual productivity growth rate occurs between 1998 and 1999, when a significant drought affected production, consistent with the results reported in Dexcel (2007). This suggests that our measured climate variables do not capture all of the important climate effects on dairy production due to their average nature. Additional variables that also capture the variability or range of temperatures and rainfall through the year may well better capture the effect of short-term droughts and other climatic effects. The greatest annual TIP growth rate occurs the year following the drought. It seems likely that productivity growth continued over this two year period and was simply masked by the significant drought conditions in the 1998/99 season. As such, the annual productivity growth rates in 1998/99 and 1999/2000 should probably be interpreted jointly. Another significant decline in productivity is observed in the 2001/02 season, consistent with Dexcel (2007), who attribute this decline to 'farmers sacrificing efficiency to maximise short term profit' (Dexcel, 2007:15).

On the whole, as noted above, annual TIP growth is below the four percent target of the dairy industry. However, as shown in Figure 1 annual productivity growth was greater than four percent in five of the fourteen years within the sample (including 1999/2000). However, annual TIP growth was negative in another four of the fourteen years within the sample (including 1998/99), resulting in the relatively low average annual TIP growth rate. So, while four percent productivity growth is achievable in any given year, it is not sustainable given the recent productivity experience of the Waikato region.

Given that these estimates of TIP growth account for changes in dairy stock numbers and land use, and control for changes in average climate, the results imply that there are limited alternatives for increasing total input productivity growth towards a higher target. Increasing stocking rates are unlikely to increase total input productivity due to diminishing marginal production with respect to the number of dairy cows (that is, an estimated elasticity of less than one). Increasing stocking rates will increase total production due to the positive elasticity of production, but the increase in production will be less than the increase in dairy stock numbers, thereby reducing observed productivity.

Similarly, increased use of land for dairy production is unlikely to increase total input productivity due to diminishing marginal production with respect to land. Like stocking rates, the elasticity with respect to land is positive and less than one. So, increases in land use will also increase *total* production, but the increase in production will be less than the increase in land use, thereby reducing observed productivity. As the sum of the coefficients on stock and effective hectares is also slightly less than one, proportional increases in stock and effective hectares will also not increase productivity.

Changes in farm management practices may offer one opportunity for increasing productivity. For instance, MacLeod and Moller (2006) note that increasing use of fertiliser and pesticides has changed the pasture rotation on dairy farms, increasing the carrying capacity and thereby the productivity of existing land, and PCE (2004) notes that much of the recent productivity growth in New Zealand agriculture can be attributed to increasing use of synthetic nitrogen fertiliser and irrigation water. However, increasing the use of inputs such as irrigation, fertiliser and pesticides has potentially significant environmental consequences (PCE, 2004). Given the contemporary policy environment, where continuing high use of synthetic fertilisers and irrigation water is being actively discouraged (for example, Cameron et al., 2010) it seems unlikely that continued productivity growth will result from continued increases in farming intensity driven by increased input use.

Broad-based technological change and innovation that increases the milk production capacity of cows, independent of the use of other inputs, is another potential source of productivity growth. For instance, recent drivers in livestock productivity in New Zealand already include significant advances in animal science including genetic and non-genetic improvements (Woodford and Nicol, 2005). Similarly, increases in efficiency of resource use offer another opportunity for productivity growth. However, recent efficiency gains have been low (for example, Ledgard et al., 2003). This suggests that the current pace of innovation-driven technological progress and efficiency gain in dairy production may be insufficient to meet a productivity goal of three or four percent annual growth. This provides a key role for policy in facilitating productivity growth in the dairy industry – additional technological change over and above that achieved over the past 15 years will only be achieved through a significant increase in the level of investment in agricultural research and development.

Conclusions

This paper investigated the productivity performance of the dairy industry in the Waikato region using panel data at the sub-regional level. The average annual growth rate of total input productivity was found to be approximately 1.2 to 1.5%.

Our results call into question the economic feasibility and long-term economic sustainability of a three or four percent productivity growth goal in the New Zealand dairy industry. The recent productivity growth performance of the Waikato region and a mature dairying region has been significantly lower than the targeted productivity growth rates of three and four percent. Furthermore, the results showed that productivity gains are unlikely to result from either increasing stocking rates or increasing conversion of land to dairy farming due to the estimated diminishing marginal production of both dairy cows and land. Productivity gains could potentially be driven by the increasing use of inputs such as irrigation, fertilizer and supplementary feeds. However, increased farming intensity driven by increased input use has significant environmental consequences and the current social and policy environment is not amenable to increasing environmental damage. The recently revised dairy industry strategy recognises that the previous productivity goals were unachievable, but notes that productivity growth will remain important to the dairy industry as it strives to remain competitive globally in the face of increasing costs.

Higher productivity growth than that observed on average over the period 1994 to 2007 can probably be only sustainably achieved through technological improvement and innovation and even then the pace of technological improvement would need to significantly increase. This can only likely be achieved through substantial increases in investment in agricultural research and development.

ACKNOWLEDGEMENTS

This research was partly funded through the Creating Futures project, which is in turn funded by the New Zealand Foundation for Research, Science, and Technology funds under Contract ENVW0601 to Waikato environment. The authors would like to thank Andrew Tait of NIWA for providing the climate data used in this analysis and to Mark Holmes, Dan Marsh, Graeme Doole, Steven Harcourt, those attending a seminar at the University of Waikato in April, 2009 and the New Zealand Agricultural and Resource Economics Society conference in August, 2009 and to three anonymous reviewers for their helpful comments on earlier drafts of this paper.

REFERENCES

Arellano M, Bond S (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev. Econ. Studies, 58(2): 277-297.

Bond S (2002). Dynamic Panel Data Models: A guide to micro data methods and practice, Cemmap Working Paper CWP09/02, London: The Institute of Fiscal Studies, Department of Economics, University College London.

Cameron MP, Barrett P, Cochrane W, McNeill K (2010). Agricultural change and social sustainability in rural New Zealand. Int. J. Environ. Cult., Econ. Social Sustain., 6(3): 77-91.

Cameron MP, Bell K (2008). Dairying in the Waikato region of New Zealand – An overview of historical statistics, Working Paper in Economics 08/13. Hamilton, New Zealand: Department of Economics, University of Waikato.

Coelli TJ, Rao DSP (2003). Total factor productivity growth in agriculture: A Malmquist Index analysis of 93 countries, 1980-2000. Agric. Econ., 32(Supplement 1): 115-134.

Coelli TJ, Rao DSP, O'Donnell CJ, Battese G (2005). An introduction to efficiency and productivity analysis, London: Springer.

Dairy Insight (2004). Strategy for New Zealand dairy farming, 2009/2020. Hamilton, New Zealand: DairyNZ.

DairyBase (2006). DairyBase user guide. Hamilton, New Zealand: DairyBase.

Dairy NZ (2009). Strategic framework for New Zealand's future dairy farming and industry, 2005-2015. Hamilton, New Zealand: Dairy Insight.

Dexcel (2007). 2005/06 DairyBase economic survey. Hamilton, New Zealand: Dexcel.

Forbes R, Johnson R (2001). Recent trends in New Zealand agricultural productivity. Australasian Agribus. Rev., 9(1).

Hughes W, Scrimgeour F, Cameron M (2005). Exploring Waikato futures: An examination of opportunities and threats, presented at the Australia and New Zealand Economic and Regional Development conference, Manukau, 27-30 September.

Johnston RJ, Gregory D, Pratt G, Watts M (2000). The dictionary of human geography, 4th ed. Oxford: Blackwell.

Ledgard SF, Finlayson JD, Gavin J, Blackwell MB, Carran RA, Weddeburn ME, Jollands NA (2003). Resource use efficiency and environmental emissions from an average Waikato dairy farm, and impacts of intensification using nitrogen fertiliser or maize silage, Proceedings of the New Zealand Grassland Association, 65: 185-189.

Livestock Improvement Corporation [LIC] (1994 to 2007, annual). Dairy statistics. Hamilton, New Zealand: Livestock Improvement Corporation.

MacLeod CJ, Moller H (2006). Intensification and diversification of New Zealand agriculture since 1960: An evaluation of current indicators of land use change. Agric. Ecosyst. Environ., 115(1-4): 201-218.

Mullen JD, Scobie GM, Crean J (2006). Trends in research, productivity growth and competitiveness in agriculture in New Zealand and Australia, paper presented at the New Zealand Agricultural and Resource Economics Society Conference, Nelson, New Zealand, pp. 24-25 August.

New Zealand Climate Change Office (2004). New Zealand's greenhouse gas inventory, 1990-2002. Wellington, New Zealand: New Zealand Climate Change Office.

Parliamentary Commissioner for the Environment [PCE] (2004). Growing for good – Intensive farming, sustainability and New Zealand's environment. Wellington, New Zealand: Parliamentary Commissioner for the Environment.

Woodford K, Nicol A (2005). A re-assessment of the stock unit system, MAF Information Paper No. 2005/02. Wellington, New Zealand: Ministry of Agriculture and Forestry.