Dairy productivity in the Waikato region, 1994-2007

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Abstract

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 increases in dairy conversion, increased intensification, and increasing use of nitrogen fertilisers, 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. Overall 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 significant technological progress, further increases in fertiliser use, land use, and/or farming intensity would be required.

Keywords

Productivity, dairy industry, Waikato.

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 percent of Waikato gross regional product (in value-added terms) and 6.6 percent of full-time equivalent employment (Hughes *et al*., 2005). Dairy farming and dairy processing combined contributed 10.1 percent of gross regional product and 8.0 percent of employment. In short, the dairy industry provides the highest 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 and 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.*, 2009). Increasing use of nitrogen fertilisers 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 three percent productivity growth across their entire value chain since 2002 (Fonterra, 2002), while the dairy industry itself had until recently a target of four percent 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 the facing of increasing global competition and rising input costs (DairyNZ, 2009). In a mature dairying region such as the Waikato, where the most suitable land is already employed in dairy farming, achieving productivity growth of four percent will likely need to be driven by (i) increasing stocking rates (i.e. increasing the number of cows at a faster rate than the growth in land use for dairying) provided there are increasing marginal returns to the number of dairy stock; (ii) increasing use of land for dairy production provided there are increasing marginal returns to land; (iii) changes in farm management practices including increased intensity of fertiliser use to improve pasture yields; and/or (iv) technological or other improvements.

There have been several investigations of 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 percent over the ten 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.[1] Mullen *et al*. (2006) estimated annual multifactor productivity growth in New Zealand agriculture at 2.2 percent over the period 1984-2001 using a growth accounting approach, Forbes and Johnson (2001) estimated annual total factor productivity growth in agriculture at 3.5 percent over the period 1985-1998 and

[1] Dexcel (2007) acknowledges that the self-selected sample will include more highly motivated farms with above average productivity.

annual total input productivity growth at 1.5 percent over the period 1972-1998 using an index number approach, while Coelli and Rao (2003) estimate annual productivity growth in agriculture at just 0.4 percent over the period 1980-2000 using a Malmquist Index approach.[2]

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 four percent productivity growth can be achieved without increased farming intensity[3] or increasing land use, by estimating 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 for 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 for by including aggregate climate data, a key input into pasture growth and hence dairy production.

Overall we show that, under a range of specifications, total input productivity growth independent of climate effects, increasing land use and herd numbers, is around 1.6 percent per year, significantly below the four percent dairy industry target and the three percent 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 four percent goal was to be met in the absence of significant technological progress, further increases in fertiliser and other input use would have been required, with consequent environmental costs. Higher productivity growth can therefore probably only be sustainably achieved through an increased pace of technological improvement and innovation, requiring substantial increases in investment in agricultural research and development.

Dairy Production in the Waikato, 1994-2007

Table 1 presents data on the increase in milk solids production, increase in dairy stock numbers, and increase in land used for dairying, for the Waikato region as a whole and for selected Territorial Local Authorities (TLAs) in the region.[4] Production of milk solids has grown by over 39 percent over the period 1994-2007, at an average annualised rate of 2.6 percent. The data in Table 1 demonstrate three important trends.

First, dairy stock numbers are growing faster than land area devoted to dairy farming (18.5 percent growth in dairy stock numbers over the 1994-2007 period, compared with 9.3 percent growth in land use), which indicates increasing stocking rates and

[2] Descriptions of the different approaches to estimating growth in total factor productivity are described in detail in Coelli *et al.* (2005), so such a description is not repeated here.

[3] Increased farming intensity refers to the increasing use of inputs (e.g. fertiliser, irrigation) to produce more food from the same area of land (Johnston *et al*., 2000).

[4] For the purposes of the analysis in this paper, the 'Waikato Region' includes all twelve TLAs that are all or partly contained the Waikato region, including Franklin District, Hauraki District, Thames-Coromandel District, Matamata-Piako District, Waikato District, Hamilton City, Waipa District, South Waikato District, Otorohanga District, Waitomo District, Rotorua District, and Taupo District.

increasing intensification of farming. This increase is apparent across all TLAs in the region, including those in which total production is declining.

Second, much of the additional production (2.6 percent annualised growth) can probably be explained by the increase in dairy stock numbers (1.3 percent annualised growth) and land use (0.7 percent annualised growth). This suggests immediately that total productivity growth may well be lower than three percent on average across the region.

Third, 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 fertiliser use?

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	Annualised	Total 1994-2007	Annualised	Total 1994-2007	Annualised	
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%
Total	**18.5%**	**1.3%**	**9.3%**	**0.7%**	**39.1%**	**2.6%**	**100.0%**

Total Input Productivity

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 estimate *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 is a measure consistent with the concept of productivity contained in previous dairy industry productivity targets (Dairy Insight, 2004), and in some previous studies of dairy industry productivity (e.g. Dexcel, 2007).

Data

The data used in this analysis were collected primarily from Livestock Improvement Corporation Dairy Statistics publications (LIC, 1994-2007, annual). These data include dairy production, dairy cow numbers, and effective land area devoted to dairying, for each of the twelve TLAs entirely or partly contained in the Waikato region. A detailed description of these data is presented in Cameron and Bell (2008). The years included in this analysis (1994-2007) are those that afforded no discontinuities or issues relating to consistency in data collection or interpretation, i.e. 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 5km to obtain the mean annual rainfall and mean temperature in each TLA in each year.

Method

All specifications were estimated from a total of 168 observations, being a balanced panel of fourteen years of data (1994-2007) from the twelve Waikato TLAs. Estimating separate equations for each TLA was initially considered; however, a dynamic fixed effects 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) below was initially specified.

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

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, p. 6);
N_{it} is the land area devoted to dairy production in district i at time t in hectares;
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;
subscripts i have a range of 1 to 12, with each number representing one of the Waikato TLAs; and
subscripts 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 autocorrelated[5]. When errors are autocorrelated, the estimates of the time fixed effects arising from 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 autocorrelation 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:

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

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 (1) (for period t) yields a dynamic representation of the production function:

$$\begin{aligned}\ln(Y_{it}) = \beta_1 \ln(C_{it}) - \rho\beta_1 \ln(C_{i,t-1}) + \beta_2 \ln(N_{it}) \\ - \rho\beta_2 \ln(N_{i,t-1}) + f(R_{it}, T_{it}) \\ - \rho f(R_{i,t-1}, T_{i,t-1}) + \rho \ln(Y_{i,t-1}) + Z_t^* \\ + (1-\rho)A_i + v_{it}\end{aligned} \quad (3)$$

where $Z_t^* = Z_t - \rho Z_{t-1}$. The resulting error term, v_{it}, is serially uncorrelated if ε_{it} follows an AR(1) process. In this paper we use OLS to estimate the coefficients in this specification.[6]

[5] The calculated Durbin-Watson statistic was 1.35. Durbin-Watson statistics substantially below 2 indicate autocorrelation of the error term.

[6] A 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

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.[7] Second, 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:

$$g_t = \frac{\exp(Z_{t+1}) - \exp(Z_t)}{\exp(Z_t)} \tag{4}$$

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.[8] Excel's Solver tool is used to find all values of Z_t, subject to the additional restriction that $\exp(Z_{1994})$ 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 will estimate 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 thus only the models using milk solids as the measure of production are presented in detail, with other models included in Appendix II. 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 climate condition. Further, interactions between temperature and rainfall were expected. As such, quadratics in the logs of these variables along with an interaction term were trialled to model the climate effects.

The statistical package used to perform the estimations was EViews version 6.

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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.

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

[8] $Z_t^* = Z_t - \rho Z_{t-1}$ represents $t - 1$ equations in t unknowns.

Omitted variables

Some obvious inputs into dairy production are notably omitted from the above 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.

First, labour is omitted from the model, and for purely pragmatic reasons: there is currently no reliable and complete data on labour input into dairy farming at the sub-regional level in New Zealand. While several datasets potentially contain some data on dairy labour, each of these data sources has significant problems necessitating its exclusion from this model. For instance:

1. Census of Population and Dwellings data – while available at the territorial local authority level and at three-digit ANZSC[9] classification level (i.e. disaggregated enough to distinguish dairy cattle farming from other farming activities), this data is only available at five-yearly intervals so is insufficient for the present panel data model.[10]
2. Agricultural Census data – as with the Census data, the coverage of this dataset is excellent, but data points are only available for 1994, 2002, and 2007.
3. Business Demography data – Statistics New Zealand collects a range of data on employment by industry; however agriculture was excluded from this series except in 1998 and each year since 2004. Further, this data only includes *employee* headcounts. This is insufficient for the estimation of labour input, which should also include the labour input from owner-operators, and should be expressed in some form of full-time equivalent employment.
4. Longitudinal Business Data Frame (LBDF) – Statistics New Zealand now provides data on employment by industry in the LBDF, although this is only available from April 1999 onwards. As with business demography data, this dataset only includes *employee* headcounts so suffers from the same problem described above.

The consequence of omitting labour input on estimated TIP growth in the dairy industry depends on the extent to which labour is explained by variation in the time fixed effects, when controlling for the other included variables. Intuitively, an upwards bias on average productivity growth could result if dairy labour has grown over time, over and above what could be expected from observed growth in dairying overall. Clearly the growth in dairy labour 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 labour is small. Furthermore, when this effect for the sub-period 2000-2007 is investigated by including a measure of labour (the dairy employee head count from the LBDF), average TIPF growth is found to be very slightly biased upwards due to the exclusion of labour. The inclusion of a labour variable showed no statistical significance and did not

[9] Australian and New Zealand Standard Classification of Occupations.

[10] Such Census data was used by Tipples *et al*. (2005) in their assessment of future dairy farm employment in New Zealand.

qualitatively alter the conclusions relating to the other variables. Thus, due to the temporal limitation the inclusion of this variable imposes on the model, labour input was omitted from the final specification.

Second, fertiliser is an important input into pasture growth and therefore should be included in the model. However, data on aggregate fertiliser use is not readily available at the sub-regional level. Irrigation is another important input into pasture growth for which data is 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. As with labour input, provided the growth in fertiliser, irrigation and supplementary feed use on average has been greater than the growth in dairying overall, then estimated total input productivity growth will be biased upwards in our estimations. MacLeod and Moller (2006) suggest that, for New Zealand as a whole, there has been substantial growth in fertiliser use, particularly since 1990, as well as substantial increases in irrigation and the use of supplementary feed, so it appears likely that an upward bias in estimated TIP growth will result. Again, this bias is likely to be small as variation in these variables is predominantly explained by scale variation.

Third, the productive capital stock such as milking sheds, tractors, etc. is not included in the model. Again, this data is not readily available at the sub-regional level. As with labour input and fertiliser use, provided the growth in the capital stock on average has been greater than the growth in dairying overall, then estimated TIP growth will be biased upwards in our estimations. Again, this bias will be small as variation in capital stock is likely to be predominantly explained by scale variation.

As noted above, the omission of labour input and fertiliser use variables are likely to bias our estimates of TIP growth in the dairy industry upwards slightly, while the omission of productive capital stock is unlikely to have a large effect on estimated TIP growth. The results of the estimations presented in this paper should therefore be interpreted with a small potential upward bias in mind.

Results and Discussion

The estimation of the model shows, quite expectedly, that the main determinant of the level of milk production in a district is the number of cows.[11] In comparison, other variables provide very little additional explanatory power. A number of selected specifications are presented in Table 2 below; all 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, 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. This specification best captures the interaction between temperature and rainfall. "White Diagonal" heteroskedasticity-robust standard errors are used to calculate the presented p-values. These standard errors are consistent with heteroskedasticity through time as well as across cross-section. The coefficients are estimated by OLS, however, given we are estimating the dynamic representation of

[11] 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 production function (Equation (3)), coefficients are estimated using an iterative procedure provided by Eviews rather than the standard OLS formula.

Table 2: Regression results and estimated total input productivity growth*

Dependent variable: ln(Milk Solids)	Regression			
Regressor	(1)	(2)	(3)	(4)
ln(Total number of dairy stock)	0.910 (0.0000)	0.901 (0.0000)	0.895 (0.0000)	0.898 (0.0000)
ln(Total effective hectares)		0.0041 (0.8333)	0.0048 (0.8056)	0.0067 (0.7397)
ln(Average temperature (℃))			-3.050 (0.2448)	-3.303 (0.0408)
ln(Average rainfall (mm/year))			-0.075 (0.9486)	-0.985 (0.0618)
ln(rainfall)*ln(temperature)			0.344 (0.1125)	0.396 (0.0532)
$(\ln(\text{temperature}))^2$			0.012 (0.9707)	
$(\ln(\text{rainfall}))^2$			-0.062 (0.2720)	
ρ (see Equation (2))	0.431 (0.0000)	0.430 (0.0000)	0.412 (0.0000)	0.395 (0.0000)
TLA fixed effects?	Yes	Yes	Yes	Yes
Period fixed effects?	Yes	Yes	Yes	Yes
Summary Statistics				
$\bar{R}^2$	0.99963	0.99962	0.99964	0.99964
F-Test - $\ln(\text{rainfall})^2$ and $\ln(\text{temperature})^2$ coefficients = 0	N/A	N/A	p=0.483	N/A
Test for redundant TLA fixed effects – Likelihood ratio	p=0.0000	p=0.0000	p=0.0000	p=0.0000
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 input productivity	**1.61%**	**1.63%**	**1.66%**	**1.66%**

* "p-values" are given below the estimates in parentheses. Period and TLA fixed effects are omitted.

As shown in Table 2, the coefficient on the log of total dairy stock numbers is approximately 0.9. This may be interpreted as the elasticity of production, i.e. if the number of dairy stock increases by 10 percent total milk solids production could be expected to increase by around 9 percent. This demonstrates decreasing marginal returns to the number of cows. This is not an unexpected finding and 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 productive resources.

In each of the specifications the number of effective hectares shows no additional power in explaining the level of production, over and above what is already explained by the number of dairy stock. Theoretically, 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 and produce more milk. However, this effect was not significant in this analysis. Two significant recent trends are apparent in land use on dairy farms. First, 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 (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 the effect of additional cows, is likely to be small.[12] The effect of area suggested by the regression estimations in Table 2 is positive but insignificant, suggesting at best that a modest increase in production arises from additional land applied to dairy production, holding other variables constant.

The climate variables must be interpreted together as they interact. The elasticity of production with respect to temperature for the minimum, average[13] and maximum levels of rainfall are estimated as:

$$\frac{\partial \ln(Y)}{\partial \ln(T)}(R)\bigg|_{R=\{R_{min},\ \bar{R},\ R_{max}\}} = \{-0.55, -0.43, -0.23\}.$$

Based on these calculations, the elasticity with respect to temperature is negative and inelastic for all levels of rainfall. If temperature increases by 1 percent, and rainfall is at its minimum over the study period, production could be expected to decrease by 0.55 percent; if rainfall is at its average, production could be expected to decrease by 0.43 percent; and if rainfall is at its maximum over the study period, production could be expected to decrease by 0.23 percent. 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 compared with drier years. However, due caution should be exercised in extending these findings to temperatures outside the relevant range of temperatures noted in Appendix I. 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[14] and maximum levels of temperature are estimated as:

$$\frac{\partial \ln(Y)}{\partial \ln(R)}(T)\bigg|_{T=\{T_{min},\ \bar{T},\ T_{max}\}} = \{-0.06, 0.05, 0.10\}$$

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 percent, and temperature is at its minimum over the study period, then production could be expected to decrease by 0.06 percent; if temperature is at its average, production could be expected to increase by 0.05 percent, and if temperature is at its maximum over the study period, production could be expected to increase by 0.10 percent. In other words, additional rainfall increases production for

[12] An interaction term between land area and the number of dairy cows proved to be insignificant in the regressions.
[13] The average utilised here is weighted by the level of production in each TLA in 2007.
[14] The average utilised here is also weighted by the level of production in each TLA in 2007.

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.

Regression (3) in Table 2 shows the specification in which quadratics in the logs of the climate variables are included. The coefficients on these quadratic terms are jointly insignificant, and this suggests that the interaction term is enough to fully describe the nonlinearity of the temperature and rainfall effects, and quadratic terms are unnecessary.

As noted above, most included variables were statistically significant. However, as the level of stock numbers explains 99.97% of the variation in the log of production in a fixed effects model (Regression (1) in Table 2), this raises the 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 shows the predicted effect of a change from the lowest to highest value of a variable, or the largest conceivable change in the variable.

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

Independent variable[15]	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	95041	107083	12.7%	14.2%
Effective Hectares	101506	101586	0.08%	12.6%
Temperature	104352	98734	-5.4%	12.0%
Rainfall	100466	103117	2.64%	52.0%

Using Table 3, the materiality of the effects of each variable can be judged. Clearly stock levels have a material effect on a near 1-to-1 basis, and temperature is a reasonably important variable with the percentage change in production around a third of the percentage change in temperature in absolute terms. Rainfall has a small effect relative to the range of possible rainfalls, while the total effective land area applied to dairying in each district seems to have a negligible but positive effect on production.

Total Input Productivity Growth in the Waikato Dairy Industry, 1994-2007

As noted earlier in Table 2, across the specifications the TIP growth implied by the models is approximately 1.6 percent per year. Average annual growth in TIP is lowest in Regression (1), at 1.61 percent, where only the number of dairy cows is included. The inclusion of climate variables increases estimated average annual growth in TIP from 1.63 percent (Regression (2)) to 1.66 percent (Regression (4)).

[15] We acknowledge that the 2008 variables are, in reality, known; we still, however, present the hypothetical predictions to demonstrate the materiality of the effects.

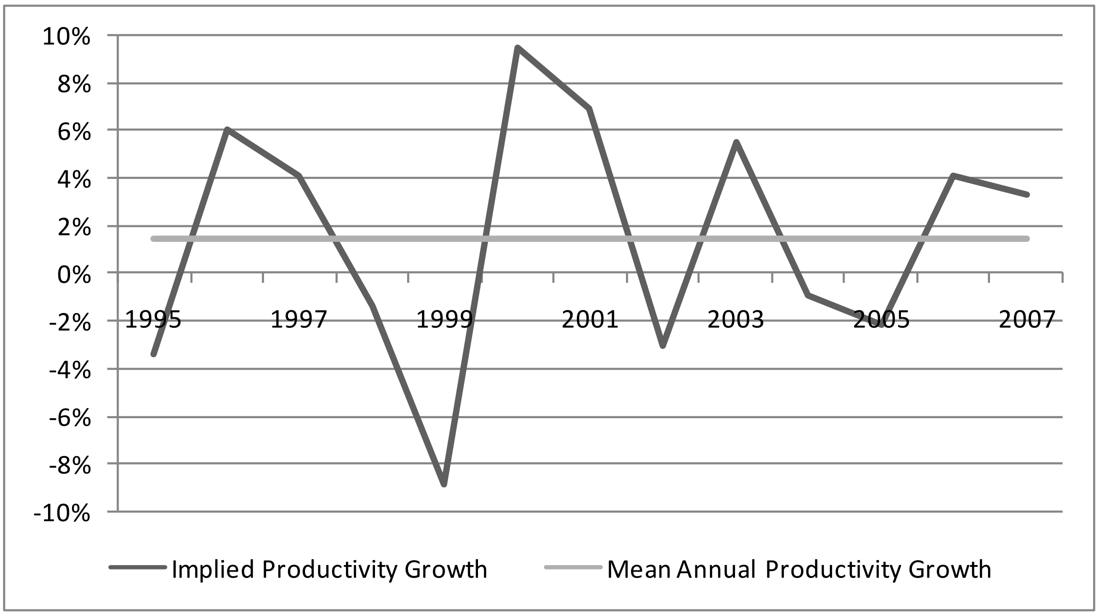
The omitted variable biases noted earlier in the paper all suggest that this estimated TIP growth is biased upwards, such that it can be concluded that estimated annual growth in TIP is significantly lower than the four percent target of the dairy industry, and the three percent target of Fonterra.[16] However, these estimates are similar to the annual productivity growth of 1.4 percent over the ten-year period to 2006 estimated by Dexcel (2007), and the long-run TIP growth over the period 1972-1998 of 1.5 percent estimated by Forbes and Johnson (2001). The productivity growth estimates in this paper likely represent 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, pp. 15).

Overall 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 six of the fourteen years within the sample (including 1999/2000). However, annual TIP growth was negative in another six of the fourteen years within the sample (including 1998/99), resulting in the low 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.

[16] $p<0.0001$.

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



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 (i.e. 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. Although the effect is insignificant, the point estimate of the elasticity of production 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.

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 (e.g. see Cameron *et al.*, 2009) 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 (e.g. see 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 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 1.6 percent.

Our results call into question the economic feasibility and long-term economic sustainability of a four percent productivity growth goal in the New Zealand dairy industry. The recent productivity growth performance of the Waikato region, a mature dairying region, has been significantly lower than the targeted productivity growth rates of three percent and four percent. 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 production of both dairy cows and land. Productivity gains could potentially be driven by increasing use of inputs such as irrigation, fertiliser 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 1994-2008 can probably only be 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.

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Appendix I: Descriptive Statistics

Total Milk Solids Produced kg (000)		Total Milk Protein Produced kg (000)		Total Milk Fat Produced kg (000)	
Mean	32199	Mean	13751	Mean	18448
Median	28958	Median	12303	Median	16655
Standard Deviation	24635	Standard Deviation	10486	Standard Deviation	14150
Kurtosis	0.071	Kurtosis	0.027	Kurtosis	0.105
Skewness	0.760	Skewness	0.743	Skewness	0.773
Range	99388	Range	42295	Range	57094
Minimum	496	Minimum	209	Minimum	286
Maximum	99884	Maximum	42504	Maximum	57381

Total Stock Units		Total area used in Dairying (ha)		Average Annual Temperature (℃)	
Mean	107496	Mean	39448	Mean	13.511
Median	103811	Median	39784	Median	13.759
Standard Deviation	80145	Standard Deviation	27607	Standard Deviation	1.160
Kurtosis	-0.122	Kurtosis	-0.385	Kurtosis	0.311
Skewness	0.688	Skewness	0.521	Skewness	-0.882
Range	300789	Range	104140	Range	5.307
Minimum	1891	Minimum	779	Minimum	10.251
Maximum	302680	Maximum	104919	Maximum	15.558

Annual rainfall (mm/year)	
Mean	1527
Median	1497
Standard Deviation	302
Kurtosis	-0.344
Skewness	0.592
Range	1329
Minimum	1038
Maximum	2367

Appendix II: Regression Results and Estimated Total Input Productivity Growth for Milk Fat Production and Milk Protein Production

	Dependent variable	
Regressor	ln(Milk Protein)	ln(Milk Fat)
ln(Total number of dairy stock)	0.903	0.894
	(0.0000)	(0.0000)
ln(Total effective hectares)	0.0059	0.0072
	(0.7577)	(0.7321)
ln(Average temperature (℃))	-3.516	-3.136
	(0.0299))	(0.0515)
ln(Average rainfall (mm/year))	-1.047	-0.935
	(0.0479))	(0.0753)
ln(rainfall)*ln(temperature)	0.419	0.378
	(0.0412)	(0.0649)
ρ (see Equation (2))(4)	0.398	0.394
	(0.0000)	(0.0000)
TLA fixed effects?	Yes	Yes
Period fixed effects?	Yes	Yes
Summary Statistics		
$\bar{R}^2$	0.99963	0.99964
Test for redundant TLA fixed effects – Likelihood ratio	p=0.0000	p=0.0000
Test for redundant period fixed effects – Likelihood ratio	p=0.0000	p=0.0000
Implied average annual growth in total productivity	**1.70%**	**1.63%**