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A study of group dynamics in the South African dairy industry: A sequential Malmquist approach

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A study of group dynamics in the South African dairy industry: A sequential Malmquist approach

This study presents a sequential Malmquist index for twenty members of an Eastern Cape dairy study group for the period 2010 to 2013. On average these farms were at efficiency levels of 95% and more during this period. The group's mean technical progress was 11% per year. This resulted in productivity growth of almost 14% per year. However, these estimates are probably inflated as they were obtained with the combination of a small dataset and a large model. The group is a success because it transfers knowledge and enables innovation. We found weak support for the belief that it is beneficial to operate mixed breed herds and showed that less intensively managed or smaller herds did better than larger herds or herds managed for the maximum amount of milk per cow. Productivity growth was positively correlated with various proxies for knowledge. It increased with self-sufficiency in hay production and expenditure on concentrates, and was inversely related to the unit hay cost. Rainfall was positively correlated with self-sufficiency but not with unit hay cost or productivity. To conclude: study groups could a useful tool for driving innovation in any industry. Innovation can happen quickly but is complex, and therefore it helps to have a single metric of progress. Good data are needed to develop accurate measures of innovation, but if available could be the difference between noting a potential disaster in time and failing altogether.

Introduction

Joining a study group can result in considerable advantages for farmers as membership can confer the benefits of innovation and technology transfer. To our knowledge no-one has attempted to quantify this kind of productivity benefit to members of a study group in the South African extension literature. Thus, this paper fills that gap.

This paper uses a sequential Malmquist index to explore the performance of the members of a study group of dairy farmers from Eastern Cape. A Malmquist index is a multi-period extension of single-period data envelopment analysis (DEA) that can identify the rate of technical progress in addition to the standard measurement of pure technical and scale efficiency for each member of the group (Thirtle, 2000). In this framework the rate of technical progress achieved by members of the group is clearly a joint benefit. The Malmquist analysis can reveal whether the same subset of group members drives progress over the study period or whether different individuals advance the frontier. A second benefit of group membership is technology transfer, which in the Malmquist framework is the degree to which inefficient farms can catch up and move closer to the frontier over time. If there are low levels of pure technical efficiency gains, little knowledge will have been shared. In a successful group, where there is a high degree of trust, individual farms could still fall behind from time to time due to adverse weather conditions (Piesse *et al.*, 2000), but will be able to catch up quickly to the frontier again because they have access to best practice information.

The aims of this analysis are to measure and explain productivity growth within a dairy study group in the Eastern Cape. Particular attention was paid to the strategy of the top performers to see if group membership had a standardising influence. The study period was 2010 to 2013. The paper proceeds as follows. The next section provides some background to the study group. Then, the Malmquist index is described, followed by a brief review of the literature and presentation of the data used in this paper. The results and discussion follow and the final section concludes.

Background to the study group

This section presents some background to the group's history and function. The group was established in the late 1970s by a farmer new to the industry. He was farming in an area considered marginal for dairy and he wished to become aware of best practice dairy farming. His fellow farmers were initially sceptical of the benefits of group learning, but by 1980 the group had settled into a core membership of about twenty farmers. Over the years membership fluctuated but at the time of the survey used in this study there were 22 people in the group, of whom 21 had belonged for the previous four years. In output terms the members have experienced significant growth since the group's inception and now account for 16% of Eastern Cape milk production and 4% of national output.

The group meets every first Tuesday of the month to discuss matters of mutual interest. Whilst there is no constitution, commitment towards regular attendance and the sharing of honest and accurate financial data is strongly emphasised. The chairmanship rotates and each declares a theme for the year. Meetings are formal, comprising of an opening, apologies, pasture feedback, an address by a guest speaker and discussion around issues pertinent to dairy farming, followed by closure and socialising.

Initially, a lot of attention was given to technical best practice, but this has since been replaced by concerns about sustainable profitability. Visits to Natal and the Western Cape broadened the focus and allowed for innovation to flourish through knowledge spillovers. Over the years presentations on animal husbandry, fertiliser use, labour management and other operational issues were conducted at the request of members. Most recently the group has responded to the government's call for organised agriculture to become involved in land reform. The group keeps meticulous records. Figures are disaggregated into a number of partial productivity measures including values per cow, per hectare, per day and per litre. Accuracy is important as a 10c saving in costs per litre of milk each year can translate into millions of Rand in profit. This group has been recognised for the quality of their data, which are now regularly used in price setting negotiations.

Perceived benefits of such a group include the ability to network and benchmark performance against leaders in the field. This enables members to adopt new ideas and innovations while receiving exposure to international trends. The exchange of experience and practice in an exceedingly dynamic industry is critical to ensuring future growth.

Methods and data

The Malmquist index

"South African Agriculture at the Crossroads: An empirical analysis of efficiency, technology and productivity" (Thirtle *et al.*, 2000) is a collected volume of papers on productivity in South African agriculture. One paper uses a contemporaneous Malmquist index, noted by the authors to be an improvement over the Tornqvist-Theil index, which is also in the book. This is because the Malmquist method decomposes total factor productivity (TFP) changes into technical efficiency changes (not considered in the Tornqvist-Theil method) and technical change. In poor years the contemporaneous Malmquist index can result in regress of the best practice frontier (Piesse *et al.*, 2000) or even intersecting frontiers (Tulkens & van den Eeckhaut, 1995; Thirtle *et al.*, 2003), while in fact it is technical efficiency that has deteriorated. The sequential Malmquist index corrects for this problem by allowing the frontier in each period to include data from previous years. Thus, for each subsequent period the frontier can only shift outwards or remain the same, while efficiency change can be positive, negative or zero.

Constructing a sequential Malmquist TFP index

In Farrell's (1957) definition of efficiency, the boundary of the input requirement set is the minimum set of inputs x^t required to produce a unit of output y^t in year t. Using a linear combination of the factor ratios of the relevant efficient farms, in this case A and B in Figure 1 below, by radial contraction an efficiency score can be computed for each farm that uses more than this minimal input set to produce a unit of output, in this case C. In Figure 1 below, the frontier is Y^t and the efficiency level of the inefficient farm C^t is $0F/0C^t$. Shephard (1953) used a distance function

$$D\left(y_i^t, x_i^t\right) = {}^{0C^t}\!\big/_{0F} \qquad [1]$$

defined on vector x^t, which is the inverse of the Farrell definition. The efficiency of the i^{th} farm is found by solving the linear programming model for the input oriented case:

$$\begin{aligned} & T\left(y_i, x_i\right) = \min \lambda \\ & \textit{subject to} \quad zy \geq y_i \\ & \qquad\qquad\quad zx \leq \lambda_i x_i \\ & \qquad\qquad\quad z \geq 0 \end{aligned} \qquad [2]$$

This model assumes constant returns to scale. It is possible to fit a concave total product function instead of the linear total product function to capture variable returns to scale, but this was not done here. To capture technical progress a time series dimension is needed. The Malmquist index is constructed from a series of distance functions that compares farms and time periods (Fare *et al.*, 1992). The contemporaneous Malmquist TFP index in terms of distance functions is defined as

$$\begin{aligned} M_i^{t+1}\left(y_i^{t+1}, x_i^{t+1}, y_i^t, x_i^t\right) &= \frac{D^{t+1}\left(y_i^{t+1}, x_i^{t+1}\right)}{D^t\left(y_i^t, x_i^t\right)}\left[\frac{D^t\left(y_i^t, x_i^t\right)}{D^{t+1}\left(y_i^t, x_i^t\right)} \frac{D^t\left(y_i^{t+1}, x_i^{t+1}\right)}{D^{t+1}\left(y_i^{t+1}, x_i^{t+1}\right)}\right]^{1/2} \\ &= \left[\frac{0C^{t+1}/0G}{0C^t/0F}\right]\left[\frac{0H}{0F}\frac{0G}{0E}\right]^{1/2} \end{aligned} \qquad [4]$$

The first ratio on the right hand size is a ratio of efficiencies expressed as distance functions of the type in equation [1], while the second bracket captures technological progress, also expressed as distance functions. Two of these terms are the same ones in the first bracket, i.e. those capturing farm efficiency levels, while the other two compare year t observations with the year (t+1) reference technology and year (t+1) observations with the year t isoquant (Fare *et al.*, 1992).

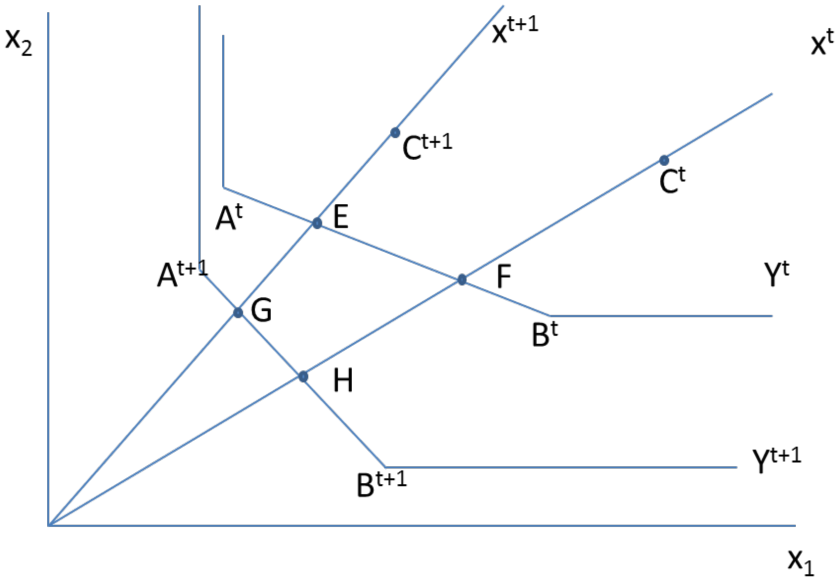

Figure 1: Efficiency and technical progress as captured by the Malmquist index (Fare et al.*, 1992).*

Expressed in terms of Figure 1 these distance functions reduce into a series of efficiency ratios. In the first bracket the change in the farm inefficiency is the ratio of $0C^{t+1}$ relative to its benchmark, 0G, divided by $0C^{t}$ relative to its benchmark, 0F. Since technological progress can be measured either on vector x^{t} or vector x^{t+1}, it can be expressed either as 0H/ 0F or 0G/0E and by convention the geometric mean of these two measures is used to capture the shift in the frontier between year t and (t+1). The technical progress distance functions

$$D^{t}\left(y_i^{t}, x_i^{t}\right)$$
$$D^{t+1}\left(y_i^{t}, x_i^{t}\right)$$
$$D^{t+1}\left(y_i^{t+1}, x_i^{t+1}\right)$$

were estimated as single-period constant returns to scale DEA programmes in CEPA's DEAP2.1 (http://www.uq.edu.au/economics/cepa/deap). The distance function $D^{t}\left(y_i^{t+1}, x_i^{t+1}\right)$ was constructed using a similar procedure except that the period t+1 input data were multiplied by a constant value of ten in order to ensure that none of these observations form part of the frontier and the resulting Farrell efficiencies were also multiplied by ten before taking the inverse to calculate $D^{t}\left(y_i^{t+1}, x_i^{t+1}\right)$. The average growth rates in percentage were calculated as the index for each year minus one (Thirtle *et al.*, 2003). Since the Malmquist index is multiplicative and the technical change component is defined as a geometric mean, the geometric mean rather than the arithmetic mean should be used.

Dairy production systems

Dairy output can be characterised either as a value or as a series of quantities. For example, Kelly *et al.* (2012) focused exclusively on milk solids per cow per hectare, Reinhard *et al.* (2000) restricted their output variable to litres of milk produced, while Murova and Chidmi (2011) used the value of milk produced. Breustedt *et al.* (2011) used profit although this appears to be counter-intuitive as their model also takes into account inputs. Other studies used multiple outputs, for example, Stokes *et al.* (2007) and Mugera (2008) both consider litres of milk produced and butterfat separately. Latruffe *et al.* (2012) disaggregate the value of milk produced and other output, and Hansson and Öhlmér (2008) allowed for a variety of outputs including milk, crops, livestock and forage. In this paper, the value of milk produced was used and income from the sale of bull calves ignored.

Table 1: Summary statistics of inputs and output (n=22).

Variable	**Unit**	**Mean**	**Standard deviation**
Milk Income	Rand	15 525 141	10 864 480
Bought hay	Rand	1 131 964	1 756 447
Concentrates	Rand	5 115 951	3 478 069
Milking Platform	Hectares	329	274
Pasture Costs	Rand	1 046 507	731 564
Cows in milk	Number	805	516
Hired Labour	Rand	987 420	712 642

Feed is the main input into dairy production. It is normally disaggregated into concentrates and hay, with the latter either produced on the farm or purchased. Farm produced hay requires seed, fertilisers, fuel and other pasture costs. The literature varies on which inputs are considered. Latruffe *et al.* (2012) chose to include utilised land, total labour hours and the value of capital and intermediate consumption. Stokes *et al.* (2007) and Mugera (2008) allowed for land, labour and cows. Although these papers exclude feed due to data limitations, it is an important variable due to its considerable impact on milk production. Reinhard *et al.* (2008) used dummy variables for years to account for technology and regulatory developments. In this paper, it was important to identify the most prevalent inputs that determine output without introducing the problem of over specification. Therefore cows, labour, land, pasture costs, and purchased hay and concentrates were used.

We were confident about the quality of the data as financial information is routinely shared between group members. All 22 current members of the study group responded to the survey, but the need for a balanced panel to construct the Malmquist index meant that the analysis had to be limited to the 21 farmers that belonged to the group throughout the study period. Convergence problems with the calculation of distance function $D^t\left(y_i^{t+1}, x_i^{t+1}\right)$ required one farm to be dropped.

Results and discussion

1. Rates and sources of productivity growth

In the Malmquist framework growth in total factor productivity results from increases in technical efficiency (catch up) and/or technical change (innovation). The averages illustrated in Figure 2 reveal that in this case innovation was responsible for most of the growth. The group's average TFP growth was 13.87% per year over the period. It varied between -1.33% to +54% per year. The farm-level details are available in the appendix.

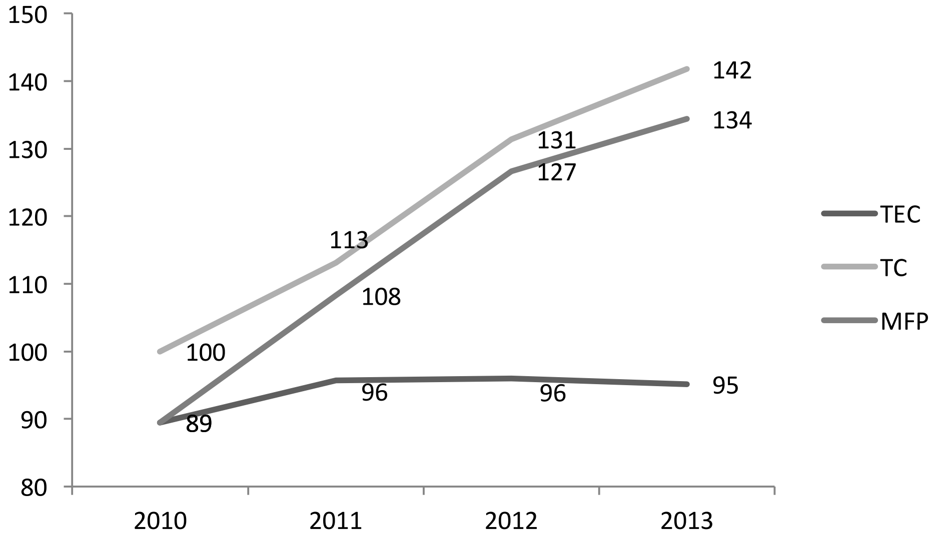

Figure 2: The sequential Malmquist TFP index and its constituent parts, Eastern Cape dairy study group, 2012-2013 (n=20).

Members of this group are highly competent and follow best practice, as can be seen from the high average technical efficiency scores recorded here. For this component of the productivity index the upper limit is 100%. In 2010, the mean score was 89% while the range was 74% to 100%. Six farms were on the frontier. In the following year the average score increased to 95%, eleven farms were fully efficient and the minimum technical efficiency increased to 85%. Technical efficiency remained more or less at the same level in 2012 and 2013.

In 2013, the minimum technical efficiency index value was lower but the number of fully efficient farms increased to twelve. The index grew at just 2.17% per year.

The second element of the productivity index, the technical change index, grew rapidly at a rate of 11.35% per year. By convention this component starts at 100% and increases from there. While a bad year could temporarily reduce how well a system performs, it is unable to affect what is possible under optimal circumstances. Hence the frontier cannot retreat. Between 2010 and 2011 the mean technical change was 13.1%. Nine farms recorded technical change of more than 10% in that year and the best performance was a 59% increase. This was probably due to a substantial increase in rainfall compared to the previous year. See the discussion below. The mean improvement between 2011 and 2012 was a more modest 4%. Just four farms achieved meaningful growth, but all four of them improved dramatically with innovation rates of 17%, 43%, 63% and 153% respectively. Between 2012 and 2013 the average rate of innovation was 5% and five farms advanced the frontier. The largest increase was 21.6%.

Not all farms exhibiting technological progress were on the frontier in the year when they contributed to advancing the frontier. For example, Farm 13 was 85.7% efficient in 2011, while it had a technical change score of 114.9%. The reason for this is that the Malmquist index does not impose Hicks neutral technical change, that is, that inputs must be reduced proportionally to increase efficiency. Therefore, theoretically Farm 13 could have operated behind the frontier in all dimensions except the one in which it contributed to technical progress.

Some of this extraordinary productivity growth is attributable to the fact that a small dataset was used to fit a frontier in which many inputs are considered. Although DEA tolerates small sample sizes much better than parametric methods, a decent sample size is still important in order to be confident about the efficiency scores. Measured efficiency increases as the ratio of observations to factors decreases. According to Thirtle *et al.* (2003), Smith (1997) reported that even when there are thirteen times more observations than inputs plus outputs, true efficiency is overstated by more than a quarter. Applying the seven factors listed in Table 1 to the panel of 80 observations approaches the territory described by Smith (1997), but the productivity indices will be high compared to other studies that either had access to larger samples or specified simpler models.

2. Group dynamics

Perceived benefits of a study group include the ability to network and benchmark performance against leaders in the field. This enables members to adopt new ideas and innovations while receiving exposure to international trends. The exchange of experience and practice in an exceedingly dynamic industry is critical to ensuring future growth.

There were five cases involving four farms with technical efficiency levels of less than 80% during the entire study period. Four of these cases were recorded in 2010. Three of the farms caught up substantially over the rest of the period. Farm 11 went from 78% efficiency to an average of 89% over the next three years, Farm 20 went from 74% to 95% efficiency while Farm 4 was 100% efficient for the rest of the study period. The exception was Farm 9 whose efficiency level deteriorated at 3.8% per year to end the period at a level of 69%. In this case poor performance was highly correlated with rainfall ($r = 0.8805$, $p = 0.1195$). On the other hand innovation was shared between members of the group and farms took turns to advance the frontier. Only five farms advanced the frontier by more than 20% in any year and no farm managed to do it twice. Nine farms advanced the frontier by more than 15% in a single year, of which three did so on more than one occasion between 2010 and 2013. See the discussion below for the main differences between farms with fast and slow productivity growth rates.

3. Evidence of a climate windfall?

The limited duration of the study raises the question of whether the period was long enough to allow for proper innovation. Instead it was thought that the technical progress identified here derived mainly from a climate windfall. The study group spans several districts and this area exhibits steep rainfall gradients from north to south and away from the coast. The period 2010 to 2013 involved two exceptionally good rainfall years of almost a thousand millimetres each and two more normal years of 708 and 673 millimetres respectively. Being a pasture study group, there was general consensus that purchasing feed is more expensive than producing it on the farm. All members have to rely on purchased feed to some extent, and to a larger degree in dry years than in wet years, but the amount required is actively kept to a minimum. This is because the group has witnessed the only member relying entirely on purchased feed go out of business.

Six farms were reported to have consistent water to irrigate almost all year round, while the remaining fourteen have to supplement farm-produced hay with more expensive purchased feed at certain times of the year. The drier farms fared marginally better than the irrigated ones; their productivity grew at 15% per year compared to just 11.2% per year growth on fully irrigated farms. The difference was not significant (t= 0.5988, p = 0.5568). Rainfall was uncorrelated with self-sufficiency (r = 0.1501, p =0.2366), unit feed cost (r = -0.1377, p = 0.2780) or productivity (r=0.0352, p = 0.7826). Feed self-sufficiency was defined as on-farm hay cost divided by the sum of on-farm and purchased hay cost. Unit feed cost was defined as the proportion of milk revenue spent on purchased and farm-produced hay. This figure excluded the cost of concentrates, which all farms must purchase. A similar unit concentrate cost was also defined and is interpreted in the next section.

4. Differences between fast and slow growers

Since rainfall did not explain the difference between high and low productivity growth rates, a series of single variable ANOVA tests were conducted across three equal sized productivity categories to investigate other possible reasons for the difference. Farmers indicated that the best way to remain competitive were to be as large as possible, to keep feed costs under control and to feed herds sufficient concentrates. The last of these could affect the value of milk produced per cow. In addition, productivity differences may possibly be a function of the type of herd. Finally, differences in management quality, here proxied by farming experience, plus years of study group membership and the number of extension visits received per year, also potentially affected productivity.

The properties of butterfat and volume are believed to be best optimised in mixed breed herds. At the time of the survey 57% of farms had already fully converted to a mixed herd, while a further five were in the process of converting. Only two farms remain with pure breed herds, one Holstein and one Jersey. Since the study period was too short for a meaningful change in herd composition, the most that can be said is that fully mixed herds recorded marginally higher productivity growth than pure herds or herds in transition (t-stat =-0.9388, p = 0.1754 on the one-tailed test). In fully mixed herds productivity grew at 14.9% compared to 12.3% in pure breed herds or herds in transition.

In Table 2 the sample was divided into three approximately equal sized subgroups according to productivity growth rates. The slowest growing group achieved a Malmquist index value of 102 in 2013, compared to a final score of

103 for the intermediate group. The fastest growing group, whose productivity grew at 28% per year, ended up on an index value of 142.

Contrary to farmers' belief, the largest herds were found to have the slowest productivity growth. The farms with the highest productivity growth had medium herd sizes that were not statistically significantly different from the average herd in the intermediate growth group. The fastest growing group in terms of productivity had the fastest growing herd sizes, although in this case the differences were not significant. Operating fully mixed herds was associated with a 2.67% higher productivity growth but this difference was not statistically significant (t = -0.4510, p = 0.6574).

Table 2: Correlates of the productivity growth rate

	Slowest growing productivity (n = 7)	**Intermediate productivity growth (n = 7)**	**Fastest productivity growth (n = 6)**	**ANOVA F**	**prob**
Productivity growth rate (%)	4.3 ± 2.8^{a}	11.1 ± 2.2^{b}	28.3 ± 13.4^{c}	67.41	1.0000
Malmquist index value for 2013	102 ± 10^{a}	103 ± 14^{a}	142 ± 67^{b}	12.09	1.0000
Herd size (# cows)	795 ± 407^{a}	546 ± 210^{b}	615 ± 245^{b}	5.01	0.0009
Increase in herd size (%)	7 ± 11	8 ± 11	12 ± 9	1.64	0.2038
Self-sufficiency in feed (%)	46 ± 22^{a}	54 ± 20^{b}	60 ± 26^{b}	2.51	0.0879
Hay expenditure (c / R milk)	18.0 ± 7.3^{a}	17.7 ± 6.3^{a}	13.8 ± 5.3^{b}	3.35	0.0404
Change in hay cost in 2011 (%)	10.1 ± 47.0	-7.7 ± 53.4	-20.6 ± 69.9	0.48	0.6265
Concentrates (c/ R milk)	30.9 ± 7.4^{a}	34.0 ± 4.8^{b}	34.4 ± 5.1^{b}	2.90	0.0609
Milk per cow (R/year)	18,132 ± 3,625^{a}	17,790 ± 2,745^{a}	16,161 ± 1, 861^{b}	3.38	0.0390
Farming experience (years)	19.9 ± 8.6	22.3 ± 11.0	23.0 ± 9.5	0.76	0.4702
Group membership (years)	14.9 ± 8.6^{a}	19.9 ± 12.0^{a,b}	21.0 ± 8.6^{b}	2.89	0.0616
Extension visits (#/year)	4.3 ± 4.4^{a}	3.6 ± 4.9^{a}	10.0 ± 13.0^{b}	4.08	0.0212
Visit from accountant (# /year)	8.0 ± 8.2^{a}	2.7 ± 4.0^{b}	7.3 ± 8.5^{a}	4.46	0.0146

Note: Superscripts refer to Bonferroni's adjustment on multiple comparison tests; the same letter signifies that means are not statistically different.

The data generally supported the farmers' ideas about the optimal feeding strategy. Productivity growth was significantly correlated with the level of self-sufficiency in hay production. According to the Bonferroni test, the difference in self-sufficiency lay between the slowest growing and intermediate groups, with the bottom approximately 15% less self-sufficient (8 percentage points) than the middle group. The self-sufficiency difference did not translate into a lower unit hay cost for the intermediate group. Like the bottom group, their unit hay cost was approximately 30% higher than that of the group with the fastest productivity growth, whose average expenditure on hay was 13.8 cents per Rand of milk revenue. The first good rainfall season (2011) resulted in a 10% increase in feed unit feed cost for the bottom group, an almost 8% decrease for the middle group and a more than 20% decrease for the fastest growing productivity subgroup. Unfortunately due to the very small sample size associated with comparisons in a single year the difference was not statistically significant. Farmers spent about twice as much on concentrates as on hay. In this case the fastest growing and intermediate groups did not try to economise and spent approximately 12.5% more on concentrates than the slowest growing groups. The unit expenditures on feed and concentrates were uncorrelated with each other (r = 0.0688, p = 0.5443). The impact of these feeding strategies on the value of milk per cow in the herd is notable. The top group achieved significantly lower levels than the two other groups, which had similar means. It suggests that when it comes to animal nutrition it might be better to economising than to attempt to maximise output.

The top performers were expected to be the most experienced and the best informed. While there was no difference in years of farming experience across the productivity performance groups, the group that achieved the fastest productivity growth had belonged to the study group for significantly longer than the bottom group. The real difference lay in how many years of farming it took before a farmer joined the group. Farmers in the top and middle groups on average joined the study group after they had been farming for just two years. It took people in the bottom group twice as long to join. The group's rigorous recordkeeping requirements probably discouraged poorer managers, at least initially, but it was interesting to note that this self-selection bias persisted after fifteen years of membership. The top performers received more than twice the number of extension visits per year than the two other subgroups, and like the bottom performers on average were paid a visit by their accountant approximately every six weeks. The use of two types of advisory services were positively correlated (r = 0.3768, p = 0.0011), but neither was correlated with farming experience or years in the group. Clearly group membership facilitates positive spillovers.

Conclusion

This paper examined the rates of productivity growth in a dairy study group in the Eastern Cape province of South Africa. If found double digit growth, which was more the result of innovation than of technical efficiency improvements. The group must be considered a success, not only because of its longevity and democratic leadership style, but also because it succeeds in transferring knowledge between farms. Most of the people in the group contributed to innovation at some point during the four year study period. Rather than a climate windfall, it seems to have been real innovation that could be due to a change in feed procurement strategy and better nutrition, or a combination of these and other factors. Now that the best performers have been identified, more qualitative work is needed to understand how particular management plans resulted in the best productivity gains.

The study yielded four main development implications. Firstly, study groups are a useful tool for building capacity in communities for farmers to manage their own progress. Almost all industries can benefit from them, especially where markets are oligopolistic and / or support services are weak. We can learn from this group that it is good idea for farmers to set up such groups for themselves, for the chairmanship to rotate and for members to set the agenda. The Department of Agriculture's extension staff, consultants and academics have a role to play in providing analytical capacity and a soundboard to such groups, but these parties should never dictate the investigation or data collection process. Secondly, innovation can happen over much shorter time frames than might be anticipated, especially if farmers are equipped with the right information and are able to engage with it in a critical way. Thirdly, innovation is complex. TFP analyses that reduce the complexity to a single metric of performance such as productivity growth are important for helping decision makers to understand their own performance compared to that of the wider group. Finally, to do so requires enough good data. The limited scope of this group has meant that productivity was probably over-stated and the results are incredibly sensitive to outliers. However, with more farmers participating in study groups there will more data and we will be able to develop more precise understandings of the drivers of productivity. This intimate understanding of the system could be invaluable in the future where climate change is likely.

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Appendix: farm level productivity growth, EC dairy study group, 2010-2013.

ID	Productivity component	2010	2011	2012	2013	GR (% pa)
1	Technical efficiency change	0.821	0.847	1	1	6.80
	Technical change	1	1.106	1.798	2.074	27.52
	Malmquist productivity	0.821	0.937	1.798	2.074	36.18
2	Technical efficiency change	1	1	1	1	0
	Technical change	1	1.077	1.114	1.179	5.64
	Malmquist productivity	1	1.077	1.114	1.179	5.64
3	Technical efficiency change	0.905	1	1	1	3.38
	Technical change	1	1.077	1.093	1.230	7.15
	Malmquist productivity	0.905	1.077	1.093	1.230	10.78
4	Technical efficiency change	0.743	1	1	1	10.41
	Technical change	1	1.191	1.399	1.427	12.57
	Malmquist productivity	0.743	1.191	1.399	1.427	24.29
6	Technical efficiency change	0.947	0.959	1	1	1.83
	Technical change	1	1.087	1.136	1.198	6.21
	Malmquist productivity	0.947	1.043	1.136	1.198	8.15
7	Technical efficiency change	0.911	1	1	1	3.16
	Technical change	1	1.114	1.120	1.362	10.85
	Malmquist productivity	0.911	1.114	1.120	1.362	14.35
8	Technical efficiency	0.834	0.866	0.981	0.970	5.16

	change					
	Technical change	1	1.084	1.089	1.189	5.94
	Malmquist productivity	0.834	0.939	1.069	1.153	11.41
9	Technical efficiency change	0.775	0.849	0.82	0.689	-3.84
	Technical change	1	1.196	1.208	1.234	7.26
	Malmquist productivity	0.775	1.016	0.991	0.850	3.13
10	Technical efficiency change	0.813	0.855	0.844	0.92	4.21
	Technical change	1	1.097	1.180	1.199	6.24
	Malmquist productivity	0.813	0.938	0.996	1.103	10.71
11	Technical efficiency change	0.78	0.925	0.878	0.873	3.83
	Technical change	1	1.058	1.059	1.144	4.59
	Malmquist productivity	0.78	0.979	0.930	0.999	8.59
12	Technical efficiency change	1	1	1	1	0
	Technical change	1	1.054	1.069	1.147	4.68
	Malmquist productivity	1	1.054	1.069	1.147	4.68
13	Technical efficiency change	0.953	0.857	0.819	0.774	-6.70
	Technical change	1	1.149	1.161	1.183	5.76
	Malmquist productivity	0.953	0.985	0.951	0.916	-1.33
14	Technical efficiency change	0.944	0.989	1	1	1.94
	Technical change	1	1.046	1.092	1.170	5.38
	Malmquist productivity	0.944	1.034	1.092	1.170	7.42
15	Technical efficiency change	1	1	0.958	1	0

	Technical change	1	1.058	1.059	1.106	3.42
	Malmquist productivity	1	1.058	1.015	1.106	3.42
16	Technical efficiency change	0.925	1	1	1	2.63
	Technical change	1	1.196	1.277	1.451	13.20
	Malmquist productivity	0.925	1.196	1.277	1.451	16.18
17	Technical efficiency change	0.806	1	1	0.983	6.84
	Technical change	1	1.099	1.183	1.205	6.42
	Malmquist productivity	0.806	1.099	1.183	1.185	13.70
18	Technical efficiency change	1	1	0.948	0.969	-1.04
	Technical change	1	1.590	1.591	1.741	20.29
	Malmquist productivity	1	1.590	1.509	1.687	19.04
19	Technical efficiency change	1	1	0.944	1	0
	Technical change	1	1.030	1.033	1.225	6.99
	Malmquist productivity	1	1.030	0.975	1.225	6.99
20	Technical efficiency change	0.736	0.988	1	0.849	4.88
	Technical change	1	1.198	3.029	3.153	46.64
	Malmquist productivity	0.736	1.183	3.029	2.677	53.79
21	Technical efficiency change	1	1	1	1	0
	Technical change	1	1.1136	1.5944	1.7392	20.26
	Malmquist productivity	1	1.1136	1.5944	1.7392	20.26