Efficiency innovation and dairy production: a multi-market case study

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Abstract

The poultry and pig industries have for many years had a focus on feed efficiency (more meat per unit of feed)**,** but the dairy industry has not paid sufficient attention to this. For the past decade Joseph Keenan and Sons has been researching and innovating to raise feed efficiency in dairying and beef production in concert with the sale of its feed mixer wagons. From 2006 onwards it has collected basic production records on the impact of its system on over 64,000 herds and nearly 1 million cows in 26 countries. This paper presents a number of separate approaches to analyse the effect of the system in the first 12-months in Australia/New Zealand, France, Ireland, Northern Europe and the UK. Over 70% of producers coming onto the system make positive margin gains, and the analysis is aimed at characterising the type and scale of response as well as to disentangling the reasons for success and failure. Two forms of graphic analysis have been developed based on a typology of response. Stochastic dominance analysis examines the overall effectiveness of the system and multinomial logit analysis is used to explain response in terms of conditioning factors.

Keywords [e.g. Feed Efficiency, Dairy, Innovation, Animal Health]

JEL code Q12, Q16, Q53

Introduction

A recent report by the FAO estimates world demand for food will increase by approximately 60% by 2050, driven largely by population and income growth. (ref) Although this is a rather sharp reduction in projected consumption levels from earlier reports issued by the FAO, it still represents a significant challenge for the food and agriculture sector – particularly in view of need to adapt to climate change, the growing demand for environmental quality and services and the uncertainty of biofuels production. Several strategies have been proposed that would increase the likelihood of meeting the projected demand growth and concomitantly reduce agriculture's adverse effect on the environment. (ref) One common element of these strategies is the improvement in agricultural production efficiency.

The needed efficiency gains will be brought about through technological and organizational innovations. In all likelihood, the private sector will play the dominant role in developing and transferring more efficient approaches to food production and distribution. Most of the private sector's innovations, however, will require strong property rights and will therefore be embodied in seeds, machines, pesticides, information and management protocols. We can be confident that the innovations developed by the private sector will offer sufficient economic incentives to farmers to encourage adoption. However, there is no guarantee that the impact on environmental quality will be adequate or even positive.

Many innovations with desirable environmental impacts are knowledge-based and as such lack strong property rights. For example, innovations in farming systems, cropping sequences, soil management or landscape reconfiguration using buffer strips or riparian zones would need to be developed and transferred, for the most part, by public agencies. Moreover, innovations of this type often lack the economic incentives to displace technologies that contribute to environmental problems because they are not sufficiently profitable for famers. As a consequence, public action in the form of subsides or regulations is often required to encourage farmers to adopt them.

The private sector has the means to develop and transfer profitable technologies to farmers that can be adopted without all the policy apparatus required for the adoption of the knowledge-based technologies. However, the question remains, if and how private firms can design and transfer profitable technologies that also contribute to the supply of environmental benefits.

This paper is a case study. We examine the attributes, development and performance of a single innovation that increases dairy production efficiency and profitability but also reduces the negative environmental impact of the enterprise. The technology was developed and transferred by a private firm. The case study looks at performance of the technology in several markets or regions that differ in terms of existing dairy production practices, industry structure, resource base, and policy environment – in a sense, a repeated experiment. Our analysis is based on a unique proprietary data base that is maintained by the firm to monitor the production and economic performance of its customers following adoption. We conclude our case study with a brief discussion of how private firms might play a stronger role in meeting the efficiency and environmental challenges that confront the agricultural sector – and still meet the demands of their stockholders.

The Technology

The technology that we are considering was developed by Richard Keenan & Company Limited. Headquartered in Borris, County Carlow, Ireland, the company has over 25,000 customers in 40 countries and employs approximately 250 people worldwide. Keenan has been manufacturing mixer wagons since 1979 when the company was founded by entrepreneur, engineer and farmer Richard Keenan. To this day, Keenan remains family owned and controlled.

The Keenan Mech-Fiber System (KMFS) is a ruminant nutrition technology that integrates hardware – a uniquely designed mixer wagon with software – sensors, IT technology, computer protocols and know-how, to produce a precision ration that improves rumen performance and animal health by reducing metabolic diseases. In addition, the technology significantly increases the ability of the farmer to observe and control feed processing, delivery and feeding performance.

The Keenan system redefines the nutritional objective for cow performance from one of forcing high levels of feed intake to one of reformulating the cow's diet both in terms of nutrient and physical (mechanical fiber) balance to take advantage of the inherent productivity of the rumen and to capture an increased amount of available nutrients in the ration. Briefly, here is a description of the KMFS components:

- *Mixer wagon.* Although feed mixing wagons have been available for dairy producers for years, the Keenan mixer relies on a unique tumbling and cutting design that produces a chemically balanced ration with optimal physical or structural properties. Sensors on the wagon capture information on ingredient weight, mixer revolutions and duration of feed processing.
- *Nutritional protocols.* Based on field experience and research trials, computer algorithms have been developed that guide the formulation of the ration – the specific feed ingredients, the amounts used, the sequence or order in which the ingredients are loaded into the wagon and the speed and duration of mixing process. Separate feeding protocols have been developed for lactating cows, dry cows and replacement heifers. In addition, the protocols produce several Key Performance Indicators (KPI's) that assist with the assessment and management of the dairy enterprise.
- *PACE.* PACE is a smart box mounted on the mixer wagon that captures data and communicates with Keenan's servers using cloud-based applications. Feed processing instructions for the farmer are sent directly to the PACE box.
- *Data Base.* Keenan maintains a data base for each client that includes information on feed processing, feeding and milk production. In addition, the company aggregates data to prepare on-demand benchmarking information for customers. The data base currently includes information from nearly 11,000 dairy herds managing more than 1 million cows.
- *Field nutritionists.* Nutritionists play an essential role in technology transfer and learning for the customer particularly during the first year of use.

The data

In this paper we use data from more than 2000 herds in eight countries collected over a 5-year period from 2006 - 2010. On each farm, measurements of average daily herd yield, milk composition, feed intake for lactating cows, milk prices and feed costs were made immediately prior to the adoption of the Keenan system and again one year later. This is not a panel data set – different farms were enrolled each year. For the purpose of comparison, we have grouped the herds into five regions. By grouping herds into regions, our analysis has some of the characteristics of a replicated experiment. The regions are as follows:

- Ireland
- United Kingdom
- France
- Northern Europe (Germany, Denmark, Sweden)
- Australia/ New Zealand

The regions differ widely in terms of resource base, industry structure and policy environment – from small grass-based dairies of Ireland to highly capitalized operations of Northern Europe.

The simple analytics of feed conversion efficiency and margin

One of Keenan's innovations is the use of feed conversion efficiency (FCE) as a performance metric or KPI. Similar performance metrics have been used for years in the swine and poultry industry – but their use in dairy production is not wide spread. Since FCE plays a central role in Keenan's assessment and monitoring of their technology, we want to develop a simple conceptual model that illustrates the link between FCE and margin over feed costs. FCE is defined as follows:

$$FCE = \frac{ECM}{DMI} \quad (1)$$

where FCE = feed conversion efficiency
ECM = energy corrected milk yield or output, in liters, kg, or cwt.
DMI = dry matter intake, in kg or lbs.

ECM standardizes the energy content of the protein and fat in milk and is based on a procedure developed by Tyrrell and Reid (1965). We use an energy content equivalent to 3.1 percent true protein and 4.0% fat.

FCE is an average product, and, as such, is only a partial efficiency measure. It is not as comprehensive as a total factor productivity or stochastic efficiency measure. (ref Battese, Barnes, Kompas) But it is relatively easy to estimate and relates the output of the primary product to the primary input.

Next, we specify the margin equation on a per head basis – essentially an enterprise or herd-level average

$$M = P \times ECM - C \times DMI \quad (2)$$

where M = per head margin over feed costs
P = price of energy corrected milk[1]
C = cost of ration on a dry matter basis

If we divide equation 2 through by ECM, we have

$$UM = \frac{M}{ECM} = P - C \times \frac{DMI}{ECM} \quad (3)$$

where
UM = the unit margin over feed costs in $/unit output – liters, kg, cwt. etc.

We can rewrite equation (3) as

$$UM = P - \frac{C}{FCE} \quad (4)$$

Equation 4 is an identity and says is that the unit margin is equal to the price of milk (ECM in this case) minus the unit cost of the ration divided by the current FCE.[2] The unit margin and the unit feed cost are particularly relevant performance measures when considering the competitive position of the dairy

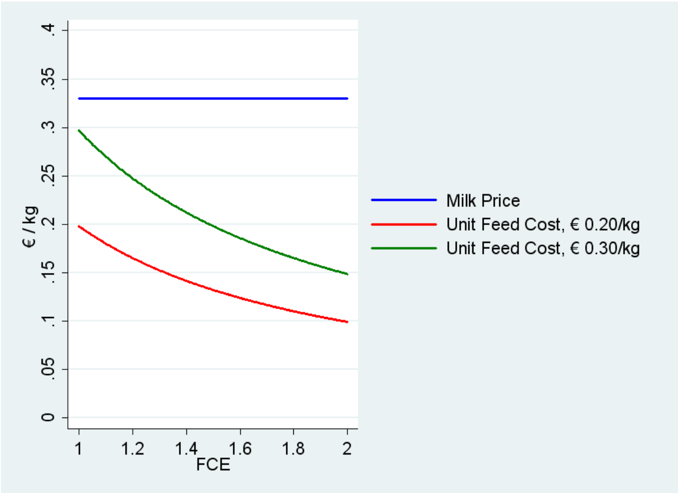
[1] The market doesn't 'discover' a price for ECM, but we can approximate the price using market-determined milk solid prices.

[2] We are assuming that the milk price and the ration cost are not functions of FCE for the moment. However, even if unit ration costs increase as a function of increasing FCE, as may be the case with higher performing herds, the relationship will still hold if the marginal increase in feed cost per unit of FCE change is less than the average cost per unit of FCE change. This situation will hold under most conditions unless extremely high cost feed ingredients are needed for higher FCE cows.

enterprise. As we will show a little later, however, changes in unit returns do not always translate unambiguously into changes in herd, per head or per hectare returns[3].

Let's consider a simple example. Suppose we let the price of milk = €0.33/liter and the dry matter ration cost = €0.20/kg. The milk price and unit feed costs, as a function of FCE, are shown in Figure 1. The unit margin in this case is the difference (or gap) between the milk price and feed cost for a given FCE. Unit feed costs decline steadily – but at a decreasing rate over a plausible range of FCE levels. In other words, a change in FCE from 1.1 to 1.2 produces a greater increase in the unit margin (or a reduction in unit feed costs) than does a change from 1.2 to 1.3.

Figure 1: Unit Margin and Feed Costs



Note that the relationships shown are identities and always hold, given the assumed prices for feed and milk. Further, it doesn't matter how FCE is increased – by increasing milk, decreasing feed or both. If FCE goes from 1.2 to 1.3, the increase in unit margin and the decrease in unit feed costs will be the same.

In Figure 1, we also show the impact of increased ration costs. When ration costs are increased to €0.30/kg, the gain from improved efficiency under a higher feed cost regime increases (the slope of the unit feed cost curve is steeper) even though margin declines. The figure also illustrates the fact that returns from increased efficiency will be less in a low feed cost environment – Ireland or New Zealand in particular. For example, a unit margin of 15 cents/kg would require an FCE of nearly 1.9 with the high ration cost assumption and only slightly more than 1.2 with lower ration costs.

Finally we relate the unit margin back to the per head or herd average margin with a simple accounting identity:

$$M = UM \times ECM \ (5)$$

[3] Grass-based dairies often prefer to specify the profit objective in terms of margin per hectare. Multiplying equation 2 by the stocking rate gives the margin per hectare. Similarly by dividing the margin per hectare equation by milk yield per hectare we obtain equation 4.

Equation 5 restates the obvious that the per head margin is equal to the unit margin times milk yield per head. We can use this relationship to show the following for small changes in unit margin and yield:[4]

1. If the change in unit margin is positive (i.e. FCE increases) and output stays the same or increases, then the per head margin increases.
2. If the unit margin increases, but yield decreases, the herd margin will increase if the percentage increase in unit margin exceeds the percent decrease in yield in absolute value.
3. If the unit margin decreases, but yield increases or stays the same, then the herd average margin increases if the percentage increase in yield exceeds the percentage decrease in unit margin.
4. Of course, if both unit margin and yield decrease, the herd margin will decrease as well.

Most producers will likely be more concerned with the per head margin since it translates directly into enterprise income. However, the unit margin is the critical issue for longer term profitability and competitiveness. As we have shown with this simple model, increasing FCE is equivalent to increasing the unit margin. And the return to increased FCE increases as feed becomes more costly.

One final thought. All of the foregoing only considers the feeding margin. Clearly when other costs or gains – milk premia, herd health improvements, new investments, labor, energy etc. are considered, the analysis becomes more complex and the simple model presented here is incomplete.

Market or regional performance of the Keenan Mechfiber system

In assessing the performance of Keenan Mechfiber technology, we focus on two basic issues: how did KMFS perform at the industry or market level compared to existing technologies and practices? And, second, how did the technology perform at the individual farm level? The first question is important because it reflects the overall benefit from adopting KMFS technology. The second question is important because it tells us how individual farms responded to KMFS and whether or not adoption leads to improved efficiency, margins or both. In this section, we will examine how adoption of KMFS technology performed at the regional level.

Variables

The production and economic data used in the analysis are routinely collected on farm by Keenan nutritionists as part of the set up procedure for the machine and then on subsequent visits to the farm at prescribed intervals. Some of the data are collected manually. However, with the introduction of PACE, the technique used to collect data changed, but the variables and measures remained the same. We use data obtained at the time the farm went on the Keenan system – that we view as a measure of the herd's productivity prior to adoption or before the impact of KMS technology is apparent. The second observation used in this analysis was made after approximately one year (+/- 30 days) following adoption.

Yield (Energy corrected milk, liters): Milk yield is obtained from milk haulers' records and converted to a per head basis by dividing total daily production by the number of cows in milk. The observed daily milk yield is then converted to an energy corrected basis using the Tyrrell and Reid (1965) procedure.
DMI (kg): Intake is determined from the loading sheet and dry matter content for each ingredient fed. The herd intake level is converted to a per head basis by dividing by the number of cows in milk.
FCE: Feed conversion efficiency is calculated by dividing yield by dry matter intake as shown in equation (1).
Daily margin: The daily per head margin over feed costs is calculated using observed milk yield and dry matter intake levels. For each herd, the price of milk and cost of feed (on a dry matter basis) used in the margin calculation is the mid-point of the actual prices received or paid by the individual farmer. By holding milk and feed prices constant within the year for a given herd, the measured change in margin can only be due to changes in milk yield, composition or feed intake. Note that prices do vary from one year

[4] For grass-based dairies, the total return to the herd would be equal to equation 5 multiplied by the stocking rate. If there is no change in the stocking rate, the relationships described below will hold. Changes in the stocking rate, however, would result in additional trade-offs between the percentage change in unit margin and yield.

to the next over the 5-year period of study. Margins are converted to Euros using prevailing exchange rates at the time the data were collected. The margin formula is given in equation (2).
Days in milk: This is the average lactation length at the time of observation for the entire herd in days. The data are obtained from the farmer's own records.
Protein (%) and fat (%): The protein and fat composition of milk reported by the producer based on analysis and reports from the milk processor.
Herd size: Number of cows in milk reported by the producer at the time of observation. Note that this measure does not include dry cows or replacement heifers.

Regional Averages

We begin our performance assessment with a look at the beginning and ending mean values and mean change over the year for several performance indicators in each of the five regions included in the study. Results are presented in Table 1. The t statistics are one-tailed tests calculated for matched observations.

The beginning output and efficiency levels varied across regions. Northern Europe had the highest yields and the greatest FCE. Ireland had the lowest initial yield, whereas France had the lowest FCE. Daily margins were highest in France and lowest in Australia/New Zealand. France had the smallest herds. Australia/New Zealand had the largest.

Looking across all regions, the mean response to adoption of Keenan technology is consistently and significantly higher milk yields, feed efficiency and margins. Intake changes are mixed and in some regions are not significant. Protein levels increased slightly and significantly in all regions. Mean fat levels increased in all regions as well, but the improvement in Northern Europe and Australia and New Zealand is not significant. Days in milk generally shows a slight increase from the beginning to the end of the year-long observation period. In most cases the increase is not significant. Australia and New Zealand and Northern Europe do show a significant increase, however. This result is somewhat surprising since the herds are observed approximately on a one-year interval. With consistent herd management practices we would expect relatively little systematic change in days in milk.
Looking across regions we see some apparent differences in starting productivity levels. Northern Europe started with higher average milk yields and FCE compared with the other four regions. Ireland and Australia/ New Zealand had the lowest initial yields and intake levels. Differences among regions in initial protein and fat levels were small.

Table 1 Mean starting and ending values by region

	Ireland			United Kingdom			France		
Performance Measures/cow/day	Start Mean	End Mean	Change	Start Mean	End Mean	Change	Start Mean	End Mean	Change
Yield (liters)	20.55	21.64	1.09[1]	23.68	24.99	1.31[1]	23.87	26.03	2.16[1]
DMI (kg)	17.54	17.49	-0.05	20.02	19.67	-0.35[1]	21.17	20.24	-0.93[1]
FCE (liters/kg)	1.15	1.23	0.08[1]	1.18	1.27	0.09[1]	1.13	1.29	0.16[1]
Daily margin/cow, (€)	4.14	4.51	0.36[1]	3.80	4.24	0.44[1]	4.55	5.35	0.80[1]
Days in milk	171.0	175.1	4.1	183.7	185.2	1.5	187.6	188.3	0.6
Protein (%)	3.33	3.39	0.06[1]	3.30	3.32	0.02[1]	3.31	3.34	0.03[1]
Fat (%)	3.88	3.94	0.05[1]	4.08	4.11	0.03[1]	4.09	4.11	0.02[1]
Average Herd Size	84			148			56		
# of observations	260			454			812		

	Northern Europe			Australia/New Zealand		
	Start Mean	End Mean	Change	Start Mean	End Mean	Change
Yield (liters)	26.82	28.16	1.34[1]	20.05	21.78	1.73[1]
DMI (kg)	20.93	20.85	-0.08	17.37	17.42	0.06
FCE (liters/kg)	1.28	1.35	0.07[1]	1.15	1.25	0.10[1]
Daily margin/cow, (€)	4.27	4.59	0.32[1]	2.66	3.15	0.49[1]
Days in milk	179.6	182.3	2.7[10]	143.6	153.1	9.5[5]
Protein (%)	3.43	3.45	0.02[1]	3.49	3.52	0.03[5]
Fat (%)	4.21	4.22	0.01	4.49	4.50	0.01
Average Herd Size	98			288		
# of observations	391			152		

Statistical significance denoted [1](1) percent level, [5](5) percent level and [10](10) percent level

Risk Efficiency

From a managerial perspective, an improvement in average or expected performance is necessary to support the decision to adopt a new technology. However it is important to take changes in risk exposure into account as well. A new technology with a higher expected rate of return may not be acceptable to the farmer if it is accompanied by increased risk.

In Table 2 we report the mean beginning and ending daily margins along with a risk index for each of the markets. One aspect of risk is the underlying volatility or randomness of returns. We use the coefficient of variation as an index to measure of this type of risk. The coefficient of variation (CV) is defined as the standard deviation divided by the mean and expressed as a percentage. It is a unit-free number that expresses the margin variability relative to the average margin. The simple result shown in Table 2 is that adoption of the Keenan technology results an increase in the average margin over feed costs and a reduction in risk as measured by the CV.

Table 2 Beginning and ending margins with coefficient of variation by market, 2006 - 2010

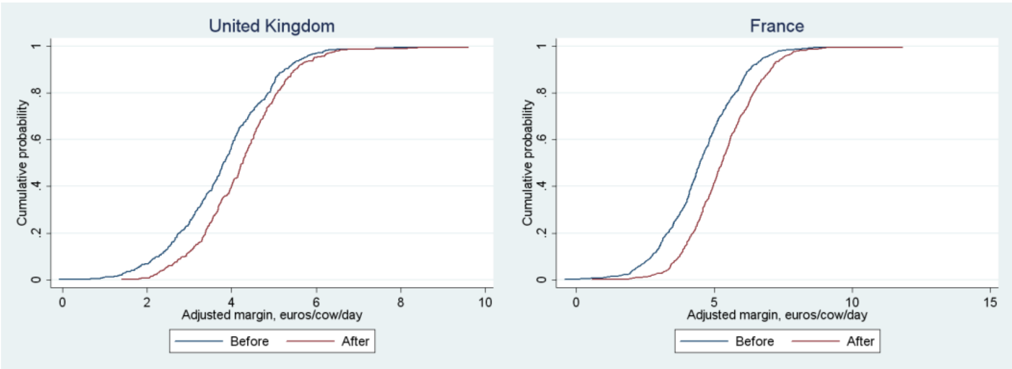
	Ireland	United Kingdom	France	Northern Europe	Australia/New Zealand
Beginning Adjusted Margin	4.14	3.80	4.50	4.27	2.66
CV (%)	38.44	31.80	31.46	47.83	47.44
Ending Adjusted Margin	4.51	4.24	5.31	4.59	3.15
CV(%)	32.54	25.22	24.52	43.72	40.75
Margin Gain	0.36	0.44	0.81	0.32	0.49
Change in CV	-5.90	-6.58	-6.94	-4.11	-6.69

A more revealing assessment of risk efficiency of the Keenan's technology can be obtained using stochastic dominance methods.[5] We use a non-parametric approach to estimate the adjusted margin CDFs for current and new technologies in each of the five regions considered earlier.[6] Recall that the estimated margin will reflect variability in yield and intake performance as well as annual variability in milk and feed prices over the study period. We show representative estimated CDFs for the UK and France in Figure 2. Stochastic dominance was tested using numerical integration techniques.

[5] For an accessible introduction to stochastic dominance methods, see Hardacker, J.B. et, al (2004.

[6] Following the suggestion of Hardacker op cit, we estimate the kth fractile for the CDF using an order statistic as K/(N+1), where N is the number of observations in the dataset.

Figure 2. Representative margin cumulative distribution functions for UK and France



The Keenan technology demonstrates first degree dominance over the existing technologies and practices in France, Ireland and Australia/New Zealand. In the UK, KMFS technology exhibits second degree dominance due to a few cross-overs at higher margin levels.   For Northern Europe, although the Keenan CDF lies to the left of the CDF for the existing technologies, the smallest observed margin for the new technology is slightly less than the smallest observed margin for the existing technology and, as a consequence, fails both first and second degree dominance tests. However, from a practical perspective, few managers would be undone by this outcome and would still choose the new technology. One caveat is important, we are using the estimated CDFs from a population of technology adopters to measure the risk and return tradeoffs faced by an individual producer. In essence this means we assume the production and price risk in the population is equivalent to the risk faced by an individual producer.

To summarize, the KMFS technology offers significant and consistent improvement in efficiency and margin across regions. Moreover, risk efficiency is also improved. However, average or market-level performance may not translate into changes in individual herd performance.

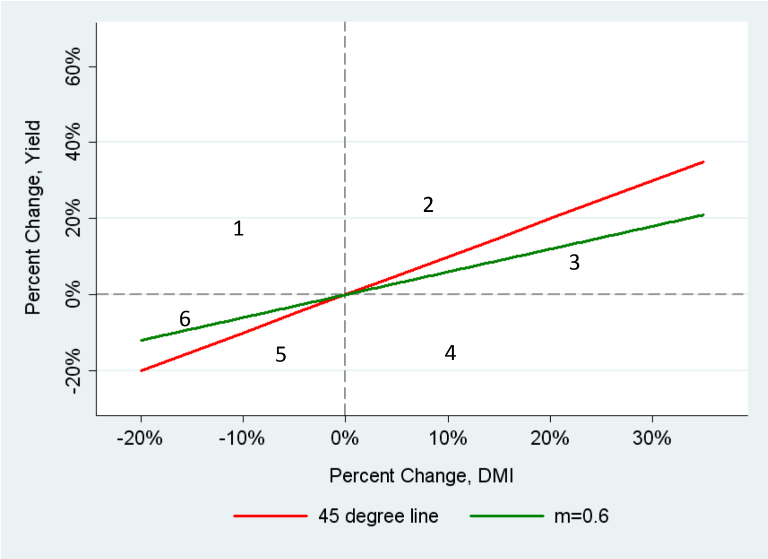
Analysis using a classification model to examine firm-level response to technology adoption

Basic concepts

Although the average response to KMFS technology is positive, it is likely that there will be winners and losers among technology adopters within each region. Understanding who gains and who does not from the adoption of a new technology is essential if improvements are to be made for specific groups of producers. In this section, we look at herd-level gains from adoption in greater detail using a simple classification model.

We start with the definition of feed conversion efficiency given in equation 1. Because FCE is a ratio, increasing or decreasing the numerator and the denominator by the same percentage leaves the ratio unchanged.   In Figure 8 we graph the percentage change in intake, DMI, against the percentage change in ECM, yield, from the beginning of the year to the end of the year. (The interval is arbitrary; it could be 90 days or after the first week.) The 45 degree line in Figure 3 shows the points where the percentage change in yield is equal to the percentage change in intake. FCE does not change along this line.   But, if the herd's intake and yield levels increase so that it moves above the 45 degree line, FCE increases. If it moves below the 45 degree line, we know that FCE has fallen. In addition, we also know that if FCE increases, the unit margin of the herd in €/liter has also increased. In other words, the 45 degree line also separates herds that improved their unit margins from those that did not.

Figure 3. Classification model based on percentage change in yield and intake



Next, we want to add changes in the per head margin to Figure 3. We start with the definition of the per head margin given in equation (2). To simplify the analysis, we assume that milk prices and unit feed costs are not affected by adoption of the technology. In other words, the producer does not receive a milk price premium following adoption and the cost of the ration does not change. With these simplifying assumptions we can determine a line that shows the percentage change in intake and yield that result in no improvement in the per head margin. This "zero margin gain" line is

$$\%\Delta ECM = \left[\frac{C \times DMI_0}{P \times ECM_0}\right] \times \%\Delta DMI \ (6)$$

where $\%\Delta ECM$ is the percentage change in milk yield from the beginning to the end of the period, $\%\Delta DMI$ is the percentage change in dry matter intake and DMI_0 and ECM_0 are the initial intake and yield levels for the herd.

Given our assumption that adoption of the Keenan technology doesn't result in any change in milk price or unit feed costs, then equation (6) states that the percentage change in milk yield, along the zero margin gain line must equal the percent change in feed consumption weighted by the ratio of feed costs to milk revenue at the time of adoption.

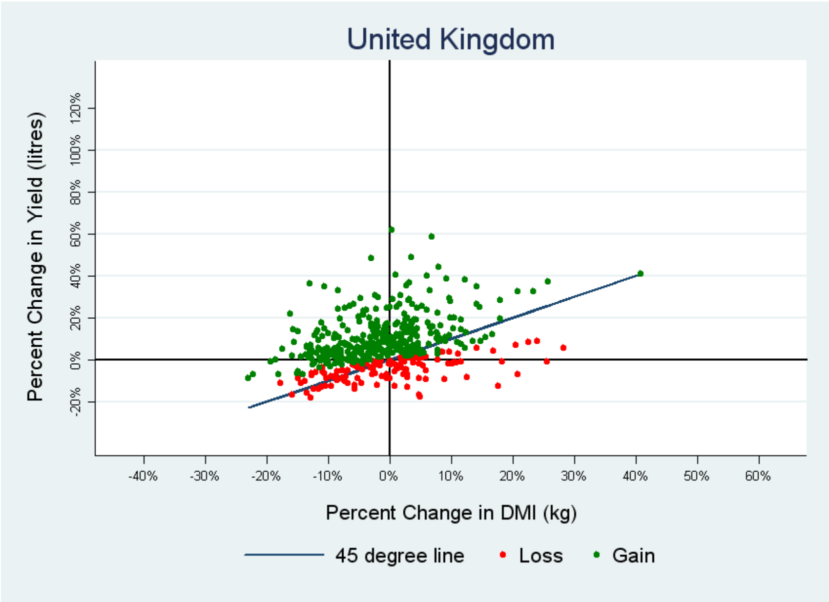
The zero-margin gain line in equation is shown in green in Figure 8. The zero-profit line goes through the origin and is drawn, arbitrarily, with slope, m, equal to 0.6 in this case to reflect a typical relationship between milk revenue and feed costs. Any farm observed above the zero-profit line has increased it's per head margin over feed costs as a result of the adoption of the Keenan system. It is important to note that the zero margin gain line is herd specific – its slope depends on the proportion of milk revenue going to cover feed costs for the herd at the beginning of the period. If the herd was rather inefficient or feed costs were high relative to milk revenue, then the margin line would rotate and become steeper. For more efficient herds or if ration costs were low the margin line would be less steep. Finally, note that the "wedges" between the efficiency and margin lines show yield and intake responses where efficiency may be improved (decline) and margins decline (improve). These results are consistent with the simple model presented earlier. Any farm that moves above the efficiency line has also increased its unit margin if prices of feed and milk are held constant. But on a per head basis it is possible to improve efficiency and reduce herd profitability if yield decreases more than intake decreases in percentage terms. The reverse is also true.

Analysis of farm-level response to Keenan technology

We use the model represented in Figure 3 to develop a simple classification model. The intuition behind the classification model is as follows: prior to adoption we can think of the farm at the origin of the graph. The question then is to predict how yield, intake, efficiency and margin will change following adoption. Or, graphically speaking, which direction from the origin will a given herd move one year or one month after adoption? Both margin and efficiency will improve if the herd moves into Group 1 or 2. Furthermore, we would expect the margin improvement for Group 2 to exceed the gain for Group 1 since milk is generally worth more than feed. Herds moving into Groups 4 or 5 would show a decrease in efficiency and margin. Herds moving into Groups 3 or 6 will likely be mixed in terms of margin improvements – some will increase, others decrease depending on the initial relationship of feed costs to revenue. Efficiency or FCE will decline if the herd moves into Group 3 and increase in Group 6.

In Figure 4 we show the representative yield and intake herd-level response following adoption for herds in the UK. The observations plotted in green are herds that increased per head margins. The herds plotted in red showed a decrease in per head margin. Plots for the other regions are similar.

Figure 4. Efficiency and margin response to KMFS technology for the UK, 2006 - 2010



The percentage distributions across the six categories are summarized in Table 2 for the five regions. For France, Northern Europe and the UK, the most frequent response is Group 1 – an increase in yield and a decrease in intake. For Ireland and Australia/New Zealand, Group 2 is the most frequent response. Herds in this group increased both yield and intake, but yield increased more than intake in percentage terms.

Table 2. Percentage Distribution of Herds by Response Group and Region

Region	Response Group					
	1	**2**	**3**	**4**	**5**	**6**
Ireland	30.1	31.9	5.7	10.2	9.5	12.3
UK	38.2	26.6	6.4	7.0	6.4	15.0
France	61.6	19.0	1.0	2.2	2.7	12.9
Northern Europe	35.6	27.9	7.7	8.6	6.4	13.6
Australia/New Zealand	23.3	47.0	1.3	2.3	12.8	12.8

In order to identify initial conditions that influence or help predict the likely response to adoption of KMFS technology, we estimated a multinomial logit model.[7] We simplify the response by pooling groups 3 – 6 into a single category. Herds in these groups showed either a decrease in FCE or per head margin.

The data set contains very limited demographic information on the herds prior to adoption. We include initial yield and FCE to reflect output and efficiency levels. Herd size is included to capture enterprise size and, to a limited extent, capital investment. We include initial fat and protein levels as proxies for breed type. We also included, but do not report, controls for year, season (quarterly dummies) and days in milk. Table 3 gives the estimated elasticities and standard errors.

In general, initial yield and FCE are the most important predictors for the performance groups in all regions. A higher initial increases the likelihood that the herd will move into Group 1 and decreases the likelihood of Group 2. For France and Ireland, higher yields predict Group 3 – herds showing a reduction in efficiency or margin. Yield did not have a significant relationship to Group 3 for the remaining regions. Increases in initial FCE decreased the likelihood of moving into Group 1 and increased the likelihood of Groups 2 and 3. . Herd size was significant only in France and Ireland. Initial fat and protein composition was included as a proxy for breed type. France and the UK show a relationship for protein as a predictor for Group 2 and 3. Fat was a significant predictor only for Northern Europe.

Comment [GMA1]: A higher initial average yield?

The results, however, are fairly consistent across regions – not too surprising since the basic biology of the cow is not affected by political boundaries. We can make some rather broad observations about herd-level response to KMFS technology:

1. Group 1, herds that increased yield, decreased intake, increased feed efficiency, unit margins and per head margins were more likely to be higher yielding but lower FCE herds.
2. Group 2, herds that increased yield, intake, FCE, unit margins and per head margins were more likely to be lower yielding but more efficient herds.
3. Group 3 – the losers in our analysis, are difficult to predict with the model. For France, they would tend to be herds with initially higher yield, higher FCE and more cows. Similar results are apparent for Ireland and Northern Europe, but the relationships are weak.
4. Herd size, given yields, FCE and other included variables, was generally not a significant explanatory variable. There is not sufficient evidence to conclude that this technology is size neutral – but if smaller herds also tend to be less efficient or lower yielding, then we might conclude they would move either toward Group 1 or 2.
5. Our proxy for breed type was a weak variable to begin with and the results support that view. We might conclude that lower fat cows in Northern Europe were more likely to move into Group 2 – Holsteins instead of Jerseys. In France higher protein herds are less likely to move into Group 2. Australia/New Zealand show a similar relationship for Group 1.

[7] The multinomial logit model was estimated in STATA. Elasticities and standard errors were estimated in STATA; calculations are made for each observation and then averaged.

Table 3. Estimated multinomial elasticities by region

	Australia/New Zealand			France			Ireland		
	Response Category			Response Category			Response Category		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Yield	3.145[5]	-2.742[5]	0.657	2.784[1]	-10.460[1]	2.655[1]	1.387	-3.644[1]	1.217[5]
	(0.014)	(0.002)	(0.425)	(0.000)	(0.000)	(0.001)	(0.164)	(0.001)	(0.049)
FCE	-6.626[1]	2.421[5]	1.495	-4.986[1]	9.747[1]	1.157	-5.873[1]	0.626	2.542[5]
	(0.001)	(0.040)	(0.216)	(0.000)	(0.000)	(0.226)	(0.000)	(0.644)	(0.007)
Herd Size	-0.509	0.0582	0.252	-0.2305	0.148	0.278[10]	0.032	-0.590[5]	0.269[10]
	(0.124)	(0.775)	(0.233)	(0.028)	(0.418)	(0.053)	(0.890)	(0.043)	(0.063)
Fat	-0.543	0.886	-0.592	0.662	0.051	-1.371	-1.356	-1.701	1.833
	(0.761)	(0.484)	(0.680)	(0.325)	(0.971)	(0.247)	(0.499)	(0.365)	(0.181)
Protein	6.797[5]	-2.018	-2.661	0.832	-6.612[1]	4.069[10]	3.047	-2.400	-0.188
	(0.033)	(0.353)	(0.259)	(0.370)	(0.001)	(0.013)	(0.254)	(0.319)	(0.916)
N		149			810			259	
Pseudo R-squared		0.175			0.157			0.166	

	Northern Europe			United Kingdom		
	Response Category			Response Category		
	1	**2**	**3**	**1**	**2**	**3**
Yield	5.041[1]	-8.175[1]	0.773	4.010[1]	-5.2792[1]	-0.531
	(0.000)	(0.000)	(0.401)	(0.000)	(0.000)	(0.459)
FCE	-10.140[1]	5.014[1]	4.186[1]	-8.358[1]	4.3729[1]	4.595[1]
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)
Herd Size	0.055	0.095	-0.087	0.041	-0.112	0.028
	(0.627)	(0.450)	(0.334)	(0.743)	(0.505)	(0.805)
Fat	1.183	-3.670[5]	1.300	1.876	0.616	-2.194[10]
	(0.477)	(0.031)	(0.316)	(0.112)	(0.659)	(0.054)
Protein	1.760	2.743	-3.057	-1.492	-4.423[10]	4.239[5]
	(0.437)	(0.292)	(0.122)	(0.432)	(0.071)	(0.022)
N		384			454	
Pseudo R-squared		0.186			0.125	

Statistical significance denoted [1](1) percent level, [5](5)percent level and [10](10) percent level

Ability to pay

Up to now, we have focused on productivity and feeding margin gains achieved during the first year following adoption. Clearly there is more to the story than this. On one hand, improvements in productivity and margin will occur in subsequent years as the technology affects dry cow performance, replacement heifers, and herd health. To that extent, our estimates of one-year margin improvements are likely conservative. (Colman et. al. 2011). But the margin gains also have to support the acquisition of the technology – machines, facilities and additional operating costs. The Keenan data base does not provide information on the actual capital adjustments herds were required to make in order to acquire the KMFS technology. A recent series of case studies conducted by Keenan suggests that the capital outlay is incremental. Most herds have much of the equipment and facilities needed to adopt the KMFS. Herds that are already using TMR technologies would simply acquire the new mixer less a trade-in. For a 100 cow herd, this adjustment would require a capital investment of €10 to €20 thousand. For herds without existing capacity for using a TMR technology – grass-based dairies for example, the capital outlay could be in the range of €60 to €80 thousand and include a tractor, the mixer and some facilities investments. The case studies suggest a range in capital investment between €100 and €800 per cow. We can use this information as a very rough benchmark, against which, we can compare the estimated maximum investment that can be supported by the observed margin gain.

In Table 4 we report the maximum capital outlay that could be made and earn either a 10% or a 20% return on equity for herds in the UK and France. The results for the other regions were similar. We make the assumption that the observed margin gain persists over the lifetime of the technology investment – 7 years in this example. Herds are partitioned into five groups based on the magnitude of the margin gain. We report the average margin gain for each group and the standard error. Capital budgeting is used to estimate the maximum capital requirement consistent with the average margin gain and the target rate of return. For herds that showed a decrease in adjusted margin following adoption of KMFS technology, we show the maximum capital outlay as NA.

Looking at the distribution of margin gains, we see 14.9% of herds in France showed a reduction in margin against 26.7% in the UK. France showed an average margin gain of 0.81€/cow/day compared with 0.44€/cow/day for herds in the UK. The estimated maximum incremental investment levels with a 10% target return range from just over €450 to nearly €4,000 per cow. Given the investment benchmarks, these levels suggest that in the technology is profitable for most of the herds in the data base that showed a positive margin response. Moreover, the results illustrate how varied the economic response and the associated ability to pay is within a region.

Table 4. Margin gain and maximum incremental investment for herds in the UK and France, 2006 - 2010

United Kingdom

Margin Gain, €/head/day	Freq.	%	Ave. Margin Gain	Capital Per Head (7 yr., 10 % return)	Capital Per Head (7 yr. 20 % return)
Less than 0	121	26.7	-0.38 (0.03)	NA	NA
0 to 0.5	133	29.3	0.26 (0.01)	€ 464	€ 344
0.5 to 1.0	109	24.0	0.73 (0.01)	€ 1,294	€ 958
1.0 to 1.5	59	13.0	1.23 (0.02)	€ 2,181	€ 1,615
Greater than 1.5	32	7.0	1.84 (0.07)	€ 3,271	€ 2,422
Total	454	100	0.44 (0.03)	€ 782	€ 579

France

Margin Gain	Freq.	%	Ave. Margin Gain	Capital Per Head (7 yr., 10 % return)	Capital Per Head (7 yr. 20 % return)
Less than 0	121	14.9	-0.58 (0.05)	NA	NA
0 to 0.5	153	18.9	0.28 (0.01)	€ 502	€ 372
0.5 to 1.0	214	26.4	0.75 (0.01)	€ 1,328	€ 983
1.0 to 1.5	177	21.8	1.24 (0.01)	€ 2,204	€ 1,632
Greater than 1.5	146	18.0	2.07 (0.04)	€ 3,674	€ 2,720
Total	811	100	0.81 (0.03)	€ 1,433	€ 1,061

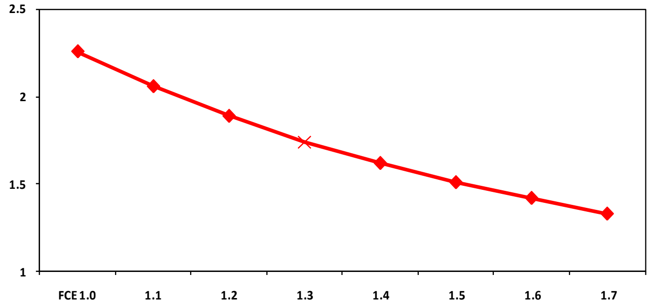
Environmental impacts

Dairy cows have been singled out as an important source of environmental degradation. (FAO ref). At the same time, growth in demand for milk products and meat are expected to grow rather significantly (FAO). A reasonable response to this dilemma is to meet increased demand with technologies that increase production efficiency and improve the trade-off between milk production and the environment. The environmental impacts of KMFS technology are discussed in Colman et al. We will summarize the key benefits:

1. Increased production of milk solids per unit of feed – as measured by FCE, reduces methane emissions as well as nitrogen and phosphorus excretion. The reason is basic thermodynamics – if you produce more of what you want, you produce less of what you don't. Figure 5 gives the estimated relationship between methane emission per unit of milk produced and FCE.
2. Reduction of metabolic disease reduces culling rates in cows and, as a consequence, reduces the size of the replacement herd. Replacements represent an economic and environmental load on the dairy enterprise.
3. Unpublished analysis conducted by the authors suggests that the combination of improved feeding efficiency and herd health can reduce nitrogen and methane production by 14 – 18% per unit of ECM.

4. Because KMFS rations rely relatively more on locally produced forages and fiber crops such as cereal straw, imported feeds are reduced as well. This reduces the importation of nutrients that must be used or disposed of in the local environment.
5. Increased use of locally produced forages can also have an impact on land use – by reducing row crop production and, consequently, sediment transport.

Figure 3. Estimated impact of increasing FCE on methane production (kg methane/100 kg milk).



The final point is to reiterate the fact that these potential environmental benefits are associated with return and risk benefits that would create an incentive for farmers to adopt the technology.

Final comments

This paper presents a case study of a single efficiency-enhancing innovation introduced into several countries or markets by a private investor-owned firm. The basic premise was that increasing (or recapturing) the efficiency of a biological system will create economic and environmental benefits. We have presented evidence that adoption of KMFS technology improves feeding margins and provides a competitive return to the farmer's investment in the technology. Because the KMFS technology is embodied in machinery, internal protocols and information, Keenan can capture some of the created value for its owners and also invest in ongoing product development and innovation. From Keenan's experience, their technology must also be integrated into the dairy value chain so that feed companies, farm consultants, lenders and processing firms coordinate and incentivize their activities in new ways. Finally, although our focus is on private investment, the food and environmental demands that will be encountered over the next two decades will require efficiency innovations from both the private and public sector.

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