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Estimating Dairy Farms' Demand for Water

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Resource Management's Act current "first come first served" method of distributing water rights is fast becoming inadequate to handle this increasingly over-allocated factor of production. Water markets or tariffs are one way to achieve allocative efficiency. To establish such markets or tariffs, it is imperative to estimate users' responses to having, for the first time, to pay for this currently largely unpriced input. This study seeks to provide a viable "starting point" estimate of the response curve to water price tariffs of dairy farmers – NZ's largest fresh water consumers – using the MPI dairy monitoring dataset. This paper suggests that under the assumptions of inelastic input substitutability, the farms' supply curves can provide an approximation of the farms' responses to at-site (irrigation cost inclusive) changes of water costs.

Keywords: water demand, dairy farms, irrigation, non-market valuation

Introduction

Fresh water is fast approaching over allocation in many catchments and regional councils are struggling to cope with the outdated first-come first served principle of allotment enacted by the 1991 Resource Management Act (Land and Water Forum, 2011). Demand management is possibly going to be required to encourage efficiency of use among competing users, either through tariffs or regulated water markets. Both systems will effectively raise the cost of water to users. Whichever system wins governmental support, it will require understanding of water users' responses to such increases. While this paper does not attempt to champion any particular method of solving the problem of water allocation, it does seek to attempt to answer the question of response to changes in water cost to New Zealand's largest consumptive freshwater users – dairy farmers. During the peak demand of summer 78% of top weekly consumption is for irrigation and 81% all volumetric annual irrigation allocation is for pasture irrigation (Aqualinc Research, 2010).

While non-New Zealand studies on the subject of water valuation are plentiful, there are relatively few published studies on the subject of water in terms of quantity (there are many on quality) in New Zealand. This is partly due to the perception that water quantity is not an issue in New Zealand and partly due to lack of suitable data (as discussed below). While it is true that in New Zealand it is not as pressing an issue as it was in Australia during the "Big Dry", there is now more and more attention given to quantity subject of water, due to increasingly conflicting demands among stakeholders.

In one of the few New Zealand studies, Grimes & Aitken (2008) address the subject and use a hedonic pricing approach to value irrigation water in a drought-prone area in McKenzie District, Canterbury. This method values irrigation through estimating the difference between irrigated and non-irrigated farms' sales price and valuation, while controlling for spatial differences, such as distance from towns, rainfall, soil and slope characteristics. They find that flatter areas with poorly draining soils get the most benefit from irrigation, suggesting that it may be due to water being able to stay longer periods in these lands. Drier areas benefit more than wetter areas. The authors join the criticism of the RMA allocation mechanism by suggesting that some farms that may benefit from irrigation cannot get access to water rights because of existing regulation and lack of mechanisms of transferring water rights. The study finds that net returns of irrigation are negative to farms due to high investment costs.

Ministry of Primary Industries [MPI] conducted an extensive study attempting to quantify the value of irrigation to New Zealand as a whole (Doak, Parminter, Horgan, Monk, & Elliot, 2004). They put the economic value of irrigation at $820 million[1] (in

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[1] This figure includes their analysis of price changes resulting from sectoral output changes.

2002/2003 dollars) by estimating a counter-factual scenario where irrigated land was hypothetically used as dry land instead. Their method is as follows: they classify all agricultural land into 14 agricultural sectors in each region, subdividing each sector into irrigated and non-irrigated portions. Next, the authors acquire the difference in yields between irrigated and dryland production for each sector in each region based on specialist opinions. Finally, they decrease the yield on the irrigated farms to match dryland yields and thereby estimate the effect of irrigation. In their subsequent analysis they use yields to estimate the impacts of new irrigation systems, and consider the effect of varying output on sector output prices.

Since the recent emphasis of fresh water management restructuring, MPI commissioned the New Zealand Institute of Economic Research to conduct a study using their proprietary Dynamic CGE model to measure the impact of increased irrigation in New Zealand (Kaye-Blake, Schilling, & Zucollo, 2010). While this study does not consider pricing of water per se, it does consider the changes in productivity of various sectors post-irrigation schemes installations, as well as the costs of installing the schemes.

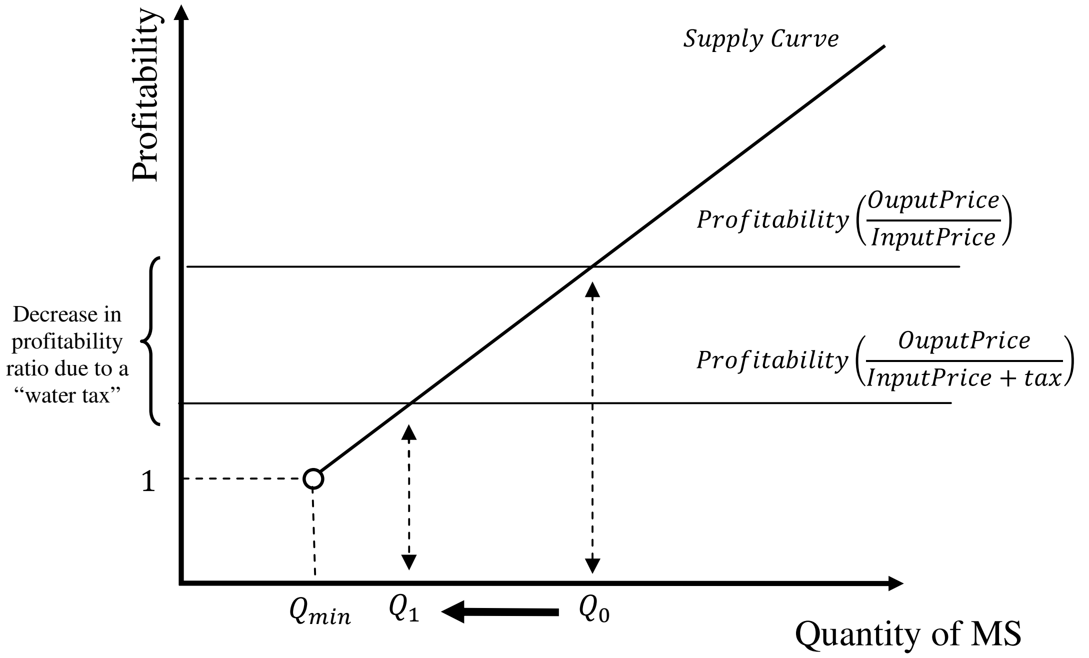
As Doak (2005) notes, “the value of water per cubic metre cannon be calculated as water use data is not yet available” (p. 2). Indeed, it was only in November 2010 that regulations requiring recording of volumetric intake of water came into effect for new consents (Ministry for the Environment, 2010). Still, this study targets to provide a starting point estimate of the farms’ short-run (annual) responses to at-site (irrigation cost inclusive) changes of water costs based on panel data analysis of MPI dairy monitory survey data.

Analytical Framework

The main premise of this study is that farmers are rational economic agents and respond to changes in incentives by altering their production, i.e. they produce more if there is more expected profit. Indeed, a qualitative study by Watters, Rowan, & Williams (2004) partially confirms this as the authors conclude that there seems to be a “wide-spread inclination for [dairy] farmers to respond to increasing prices through increasing input and production outputs” (p. 22). As one of their respondents suggests “if payout allows” s/he maintains or increases the use of fertilizer and brought in feed to increase the milk solid [MS] production.

Perhaps a more economically rational observation is that higher profitability (measured as an output-input price ratio) induces higher levels of production, and vice versa. Hence, an increase in the cost of water would essentially be equivalent of a reduction in profitability, thus lowering the incentivea for extra production. One possible way to visualise this relationship is considering what would happen if a hypothetical water tax for each milksolid sold was introduced on the portion of the farm’s supply relying on irrigation (Figure 1). If the output price remained unchanged, quantity supplied would fall from Q_0 (quantity of MS produced due to irrigation prior to water tax) to Q_1 (post introduction of water tax). An important feature to note is that production due to irrigation would cease altogether if output/input price ratio falls below unity since the cost of paying for one unit of production would exceed the revenue received (i.e. average variable cost would become higher than marginal revenue). Note too, that the quantity of MS produced in the rain-fed production process would remain unchanged.

Figure 1. Effect of a Hypothetical Water Tax on Production



It follows that to find a relationship between the volumetric cost of water and farmers' responses one first needs to know:

1. the relationship between the quantity of water required for production of each milksolid;
2. the relationship between the output variations due to changes in the expected output-input price ratio.

The relationship between a volumetric unit of water and corresponding yield of kgMS production can be derived from the literature on pasture response to irrigation. It is conditional on the slope of the land, soil type, irrigation rates, grass type, fertilizer regime, climatic conditions as well as time of the year (Brown & Haigh, 2005; Thomson, 1996). For the purposes of parsimony, average responses will suffice for now. In the study of predicting future demand for irrigation in Waikato, Brown & Haigh (2005) find that, on average, an extra mm of irrigation yields an additional 9.3kg Dry Matter per hectare (DM/ha). In Canterbury, using an average of 7 irrigations of 100mm per season yielded an increase from an average of 6.7t DM/ha to 11.9t DM/ha, or 5,200kg / 700mm = 7.4kg DM/ha per 1mm (McBride, 1994). In Taranaki, the average yield response to 1mm of irrigation is similarly 7.56kg DM/ha/year, ranging from an average across zones of 3.9kg to 10.1kg DM/ha/year (Rout, 2003).

In terms of relating DM to milksolids, numerous factors affect cow productivity, such as cow weight, breed, distance needed to walk, topography of pasture, etc (as well as the quality of DM itself). DairyNZ (2010) suggests that annual dry matter requirements for 350kgMS/year producing Jersey weighting 400kg that walks 4km/day on flat land and is in milk for 270 days requires 4.6t DM + 6% of wastage = 4.9t DM. Hence, each kg of DM would yield 350/4,876 = 0.072kgMS. It follows that, *on average and conditional on a range of factors*, if 1mm of irrigation yields 7.4kg DM/ha annually (in Canterbury), it is transferred into 7.4 * 0.072 = 0.52 MS/ha/year. Since 1mm on a hectare is equivalent to 10m^3, then it follows that it takes approximately 10/0.52≈20m^3 of irrigated water to produce 1kgMS.

The relationship between the change in the expected output-input price ratio and corresponding change in output is the subject of subsequent data analysis. It seeks to establish a correspondence between expected profitability (as measured by the output-input price ratio) and its effect on a farm's output in terms of kgMS, while controlling for other factors. Once such relationship is established, it would mean that the coefficient on the output-input price ratio could be interpreted as the expected change of an average farm to a change in profitability, due to an introduced "water tax wedge". Since only a portion of production on farms is due to irrigation, the effect would only apply to that portion (rain-fed production would remain unchanged).

Data

The data has been provided by the MPI for the purposes of this research[2]. It is an unbalanced panel data of a sample of dairy farms throughout New Zealand's main dairying regions over 11 financial years (from 2000 to 2011), with a total of 1,508 observations (Table 1). Farm-level data available and used includes the total kgMS produced, effective farming area (in hectares), number of cows and total expenditure (see Table 2 for summary statistics). Additional series, namely precipitation, price indices and payout data were merged as described below.

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[2] Special thanks to Phil Journeaux for his help on the subject of the Dairy Farm Monitoring Survey.

Table 1. Cross-Tabulation of Farms in the Study

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
CANDY	20	20	20	20	20	20	20	20	30	30	25	25
NHLDY	20	20	20	20	20	20	20	20	25	25	20	20
SNIDY	0	0	0	0	0	0	0	0	28	30	20	20
STHDY	20	20	20	20	20	20	20	20	30	30	25	25
TARDY	20	20	20	19	20	20	20	20	26	35	25	25
WSADY	20	20	20	20	20	20	20	20	50	50	45	45[3]

Table 2. Summary Statistics

	cows	**kgMS**	**area**	**expenses**
Mean	384	137,683	153	438,597
Median	330	110,116	127	330,518
SD	236	101,130	95	367,731
Kurtosis	7.95	8.60	6.86	8.55
Skewness	2.26	2.41	2.03	2.39
Min	79	15,000	30	56,723
Max	2,200	800,000	884	3,339,402

Output-Weighted Expected Payout and Profitability Ratio

New Zealand dairy farmers' largest source of income is through the sale of MS to their co-operatives, the biggest being Fonterra. The majority of famers do not have the scale to exercise market power, and hence are bound by the payouts. The payout per milksolid consists of a farmgate milksolid price as well as a profit share (Distributable Profit - formally known as "value added components") from the profit of value-added activities of the co-operative.

Although farmers receive advance payments to aid they yearly cash flow, the final payout is usually announced well into the next production season, hence it has no effect on farm production in the corresponding milking season. What motivates short-run variability in the production is the forecasted payout – or how much the co-operative predicts the final payout to be. After the opening forecast at the start of each season, the co-operative updates it forecast, which is driven by such factors as currency fluctuations, international dairy auction prices as well as the expected profit from the value-added activities.

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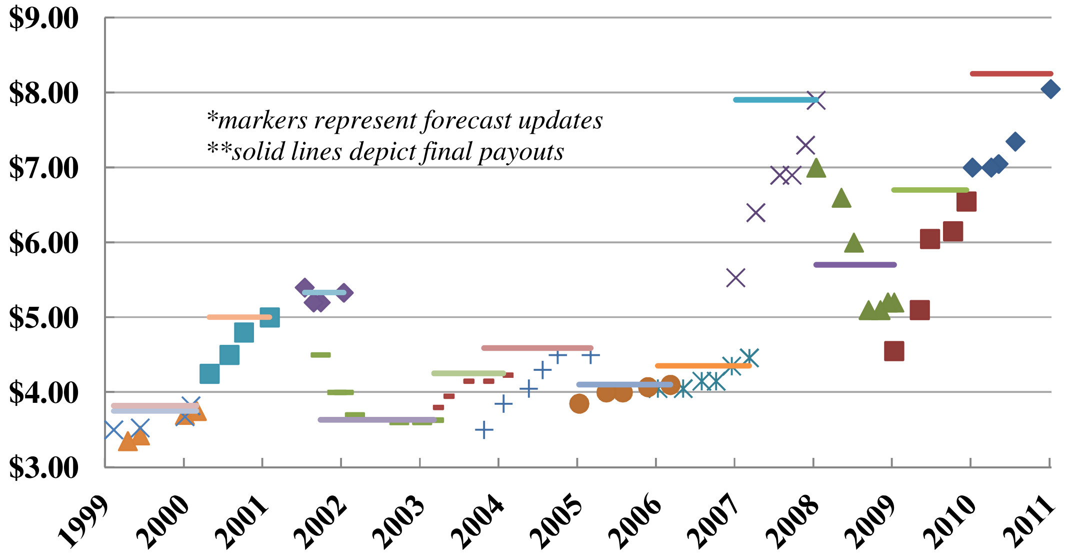
[3] **CANDY** – Canterbury Region; **NHLDY** – Upper North Island; **SNIDY** – South of North Island; **STHDY** – Southland; **TARDY** – Taranaki; **WSADY** – Waikato/Bay of Plenty.

As per Figure 2, initial forecasts sometimes substantially differ from the final payout. For instance, in the 2009/2010 season, the opening forecast was only $4.55 whereas the final payout was actually $6.55, making the actual payout an inadequate measure of farmer short-run incentive.

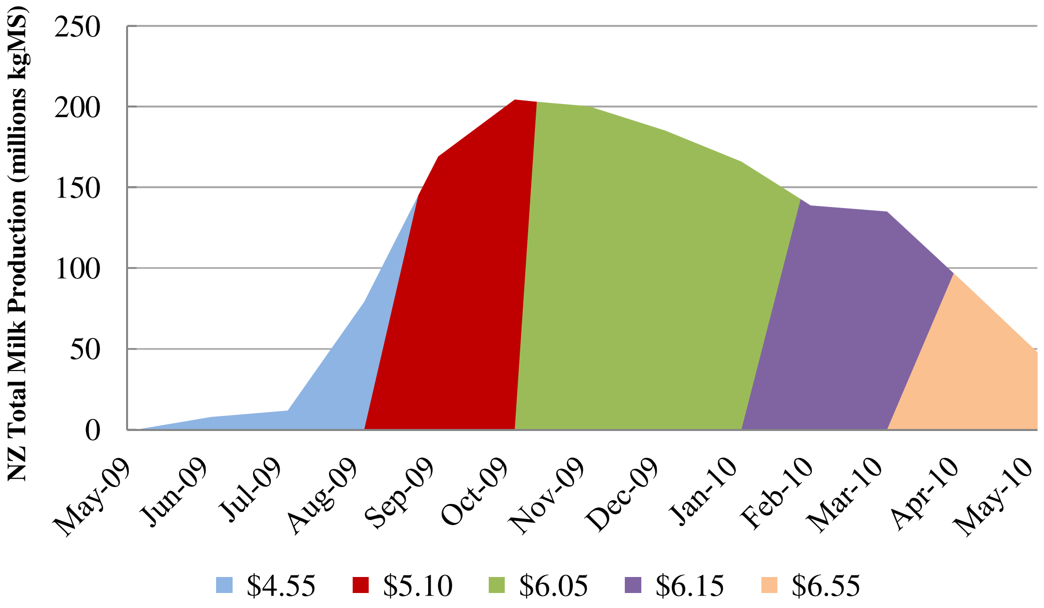
Figure 2. Forecasted vs Actual Payout



Source: NZ Herald 1999-2012; Fonterra 2000-2012

To obtain a more reliable incentive indicator, an output-weighed forecast (OW forecast) measure was developed, where the forecast was weighted by the quantity of MS produced when each forecast was in effect. For instance, the above-mentioned opening forecast for the 2009/2010 season was effective up to 22-September 2009 when the forecast was increased to $5.1 Using the end of August (79,240) and end of September (169,206) total New Zealand kgMS production, a linear extrapolation resulted in an estimated 106,491 kgMS produced from August 31 to 22 September, and a cumulative of 205,340 kgMS since the start of the season on June 1st 2009, or 14% of the 1,438,496 MS produced in the 2009/2010 season. Hence, for 14% of the total production, the expected payout was $4.55 (see Figure 3). Likewise, it was $5.1 for 23%, $6.05 for 43%, $6.15 for 17% and $6.55 for 4%, resulting in average weighted expected payout for the season of $5.65. Detailed data on New Zealand-wide total MS production was available only for seasons 2008 through 2011, hence for the other years the average of four years of available total production record was used. Table 3 summarizes the disparity between the final payout and the OW forecast.

Figure 3. Output-Weighted Forecast Estimation



Data Sources: DCANZ (2012); NZ Herald 2009 & 2010

Table 3. Output-Weighted Forecast vs Actual Payouts

Season	O-W Forecast	Actual	Difference
2010/2011	7.19	8.25	1.06
2009/2010	5.65	6.70	1.05
2008/2009	6.05	5.70	-0.35
2007/2008	6.60	7.90	1.30
2006/2007	4.10	4.35	0.25
2005/2006	3.98	4.10	0.12
2004/2005	4.18	4.59	0.41
2003/2004	4.03	4.25	0.22
2002/2003	3.68	3.63	-0.05
2001/2002	5.30	5.33	0.03
2000/2001	4.43	5.00	0.57
1999/2000[4]	3.40	3.75	0.35

While the nominal payout more than doubled between 1999/2000 and 2010/2011 seasons, the costs of production and costs of living have likewise risen (Figure 4). The

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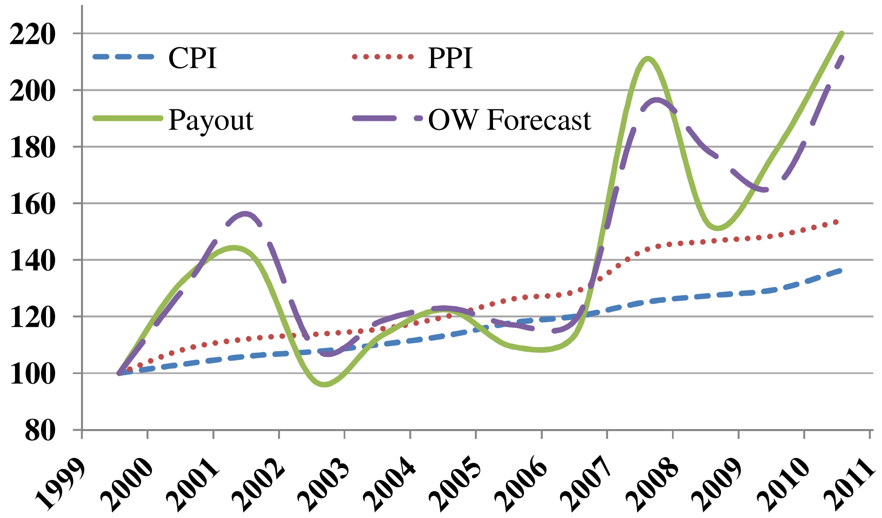
[4] For the 1999/2000 season the NZ Dairy Group forecasts and final payout were used for the purposes of the analysis since this was prior to the establishment of Fonterra.

cost of producing (Producer Price Index (PPI)) has risen at a substantially faster pace than cost of living (Consumer Price Index (CPI)).

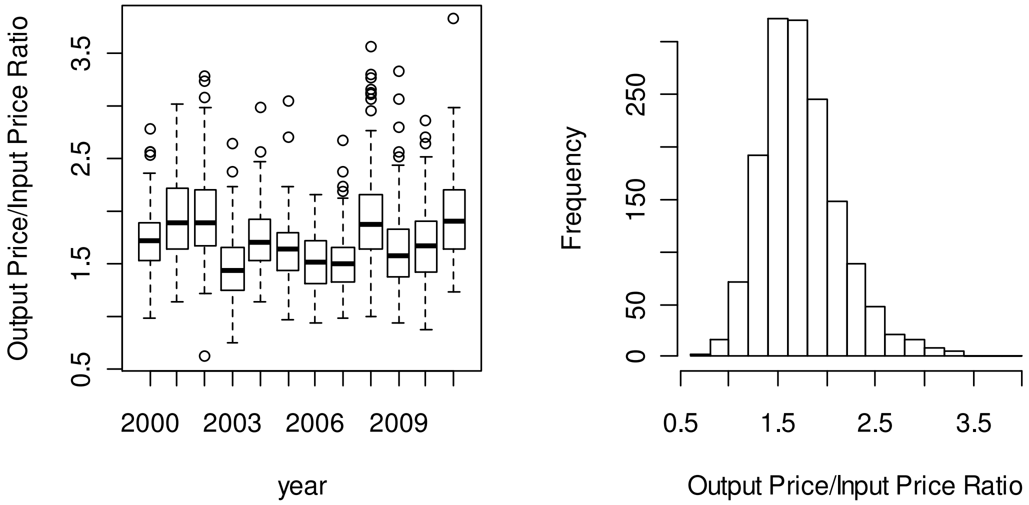
Figure 4. CPI, PPI and Payout Indices (1999=100)



Data Sources: Statistics NZ (2012); NZ Herald 1999-2012

To adjust for the changing rates of price increases, as well as to mitigate for multicollinearity which would arise since the year and region dummy variables would be perfectly collinear with the same payout experienced by each farm, an output price / input price ratio (O/I ratio) was calculated for each farm. This ratio could be interpreted as profitability ratio, and hence changes in profitability due to either changes in payout or costs per each MS could be interpreted as having the same effect. In lieu of higher payout (output price) or lower expense (input price), the ratio would increase and hence motivate higher levels of production – a supply curve. Moreover, logistic transformation of the ratio could be interpreted as price elasticity of supply Tauer (1998). As per Figure 5, the expectation adjusted O/I ratio is centred just above 1.5 and is relatively steady over time except for the low payout year of 2003 and high payout year of 2008.

Figure 5. Output Price/Input Price Ratio across Years and its Distribution



Precipitation

For each dairy region in the sample a representative weather station was selected from NIWA weather database and corresponding monthly total rainfall (in mm) was obtained. For each region and each production season, months November through April were selected, deemed to have the most impact the variation in production. Because both, extremely wet (as in 2003) and extremely dry (in 2008) seasons both can potentially negatively affect DM growth, the rainfall variable for each region was first centred on the mean in each corresponding region, then split into negative and positive deviations from it.

Results

To derive the relationship between the O/I ratio and output, total production of kgMS in a year from individual farms was regressed on the available explanatory variables. Table 4 summarizes the results of the model. The following outlines each variable and their significance.

The number of cows (*cows*) was included to control for the scale of farms. Having the most explanatory power, the coefficient suggests that an additional cow can add an extra 413 kgMS. This is somewhat larger than the average MS production per cow in the sample (344), but in line with the averages from recent years. Interestingly, variables attempting to control for the intensity of dairying – *stocking_rate* and *area* were not found to be statistically significant in most regressions. While farming area is highly correlated with the number of cows (r=0.82), suggesting low efficiency due to multicollinearity, lack of explanatory power of the stocking rate is harder to explain.

Table 4. Regression Output

Regressor	Dependent Variable: **Total kgMS**
cows	413*** (7.38)
dry_year_rain(mm)^{CR}	52.8*** (11.1)
wet_year_rain(mm)^{CR}	-26.0** (10.0)
OI_ratio	10,865*** (1,675)
OI_ratio × *stocking_ rate*^{C}	-4,183*** (964)
OI_ratio× *area*(ha)^{C}	-48.7*** (10.9)
SER	23,390
R^2	0.947

Robust standard errors are given in parentheses under coefficients. Individual coefficients are statistically significant at the **1% or ***0.1% significance level. ^{C} denotes that the variable was centred by subtracting the mean of all observations in the sample, while ^{CR} indicates that the variable was centred with the mean of the corresponding region. 1999/2000 season and CANDY region dummy variables were omitted from estimation to avoid perfect multicollinearity with the intercept. Heteroskedasticity adjusted F-statistic testing whether all year dummy variables are zero is 5, (p-values < 0.0001); and 44.0 testing that all region dummy variables are jointly insignificant.

Next, positive and negative deviations from the region's average rainfall for months November through April were added to control for weather. Note that the coefficient on extra mm of rain in a dry year above the average (*dry_year_rain* (mm)) is 52.8, which, when divided by the average farm size (153 ha) yields a marginal effect of 0.35. While this is a somewhat smaller effect than that of irrigation reported earlier (0.52), it is as expected since precipitation does not follow a schedule for optimal DM growth, but is a good indicator that both coefficients are of relatively the same magnitude. The effect of rain in a wet year has expected sign and is less than half the size of the effect in a dry year.

The model also includes dummy variables for time and regions specific effects. The rationale behind this fixed effects specifications is that in each year there are bound to be explanatory effects omitted that are shared among all farms (such as economic outlook and confidence), whereas some effects are likely to remain constant across time, but shared among neighbouring farms (eg. regional climatic attributes). Inclusion of the dummy variables ensured that these time and region specific effects (although unobserved) were controlled for.

The coefficient on *OI_ratio* has an expected sign, but a comparatively low magnitude, suggesting a low responsiveness of farms to changes in output and input prices. Logistic transformation of both sides of the regression yielded a coefficient of 0.16, which can be interpreted as the price elasticity of supply – a 1% change in price ratio triggers only a 0.16% change in quantity supplied. This inelastic response suggests that farms have low flexibility in the short-run, due to constrained fixed resources (number of cows and land) and diminishing marginal returns to variable inputs (irrigation, fertilizer and feed).

The size of the farm (*area*) and dairying intensity (*stocking_rate*) were included as interaction terms with the *OI_ratio*, and their significance suggests that the effect of expected profit varies with farm sizes and farming intensity. Each interaction was centred by subtracting their respective means, so that interpretation of *OI_ratio* can be taken as that of a farm with an average stocking rate and farm size. Smaller farms and those with lower farming intensity tended to be more flexible when output/input prices changed.

The effect of the O/I ratio is estimated to be 10,865 kgMS for a unitary change in the O/I ratio for an average farm. Since interaction terms were included, it must be qualified by stating that coefficient holds for a farm of 153 hectares and a stocking rate of 2.64. This reduces to approximately 10,865/153ha = 71kgMS/ha. The marginal effects of a unitary increase in the O/I ratio for larger/smaller farms as well as those with higher/lower stocking rate can be calculating by adding the average O/I ratio effect with a product of required values for area and stocking rate and their respective coefficients – see Table 5[5].

Table 5. Marginal Effects of O/I Ratio with Interaction Terms

		stocking rate		
		1.60 *(bottom 10%)*	**2.64** *(mean)*	**3.47** *(top 90%)*
***area* (ha)**	**68** *(bottom 10%)*	19,375	15,005	11,550
	153 *(mean)*	15,235	10,865	7,409
	268 *(top 10%)*	9,626	5,256	1,801

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[5] Note that coefficients are for centred variables, hence, the bottom 10% multiplier for stocking rate interaction term, for example, is 1.60 - 2.64 = -1.04.

Interaction terms suggest, as expected, that smaller farms are more responsive to changes in profitability, and that less intensive production is more responsive. This makes economic sense as there is inevitably “excess capacity” within farms with lower stocking rates, and they are more likely to be flexible if there is a short-run change in either input or output prices.

Application to Water Demand

To predict a response of a farm to an increase in a volumetric pricing of pasture irrigation water, it is first necessary to include a number of parameters and assumptions, some of which may be changed in accordance to application requirements. As an example, suppose there is a farm with the following attributes:

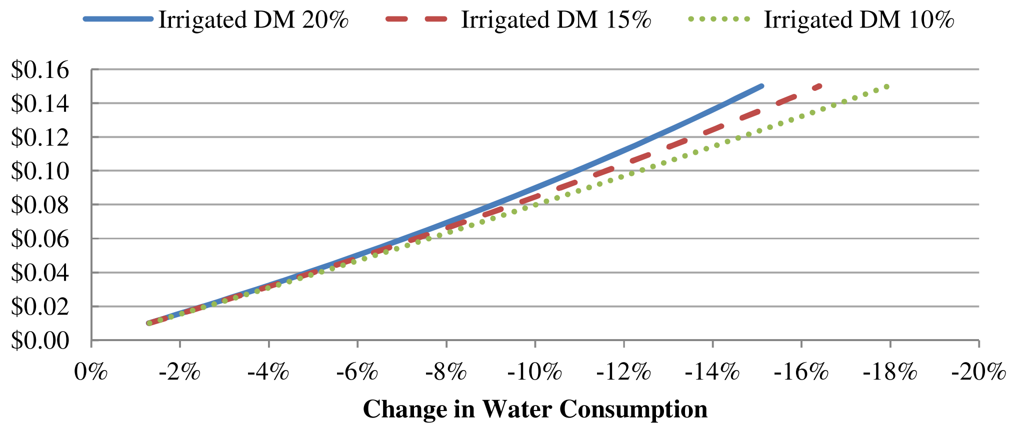
Number of cows	404
Farm Size	153 ha
- ***Stocking Rate***	*2.64*
Payout	\$6.8
Cost / MS	\$2.79
- ***O/I Ratio***	*2.44*
MS Production	140,000
Pasture Irrigation Response	7.4kg DM/ha/mm
Proportion of DM grown due to irrigation	10%
DM requirements/cow	5 tons

Each cow requires 5 tons of DM to produce 140,000/404=347 kg of MS, so each kg of DM yields 347/5,000=0.0693kgMS. Since 1mm/ha of irrigation produces 7.4kg DM/ha/mm, it results in 7.4*0.0693=0.512kgMS/ha. 1mm/ha of irrigation is equivalent to 10m^3, then it takes 10/0.512=19.51m^3 to produce 1kgMS. In absence of water tariffs, the farm would consume 19.51*0.1*140,000=273,140m^3 of water.

Now suppose a 5 cent/m^3 tariff is introduced. Assuming no input substitution (e.g. for brought in feed), the farm now faces a 273,140*0.05 = \$13,657 bill for irrigation water. The overall farm working expense / MS rises from \$2.79 to \$2.79 + \$13,657/140,000 = \$2.89. The O/I ratio falls from 2.44 to \$6.8/\$2.89=2.35, hence the O/I ratio changes by 2.44-2.35=0.085. Using the coefficient on the O/I ratio, the consequent predicted fall in the production is 0.085*10,865 = 924kgMS. Since the increase in cost is only for the irrigated production, for the farm to produce 924 fewer kgMS, it would require 924 *19.51 =18,032 fewer m^3 of water (or 18,032/273,140 = 7% less water).

This methodology can be extended if there are any changes in the assumptions. For instance, Figure 6 traces the response of various increases of water prices assuming different proportions of DM grown due to irrigation. Those with less irrigated DM growth have a more elastic response, particularly with higher increases.

Figure 6. Change in Water Demand vs Change in Price Increase (per 1 m^3)



Conclusion & Limitations

This study's aim was to produce a "starting point" estimate of the response curve to water price tariffs of dairy farmers and should be treated as such. It is based on a number of restrictive assumptions including that all farms employ the same production function, there is linearity in DM yield in response to irrigation, and there is no substitution among factors of production.

In reality, faced with increasing water costs farmers are likely to substitute to brought-in feed and water usage efficiency technologies. Allowing for substitution would theoretically yield much sharper responses (i.e. more production would be shifted towards using brought-in feed, less irrigated water). Indeed, in Australia farmers have to decide every year before the start of production season whether to invest in "temporary water" and make a loss if the year ends up to be wet, or risk it and face the prospect of having to purchase expensive feed (O'Connor, n.d). Further study should be carried out to examine the trade-off between brought-in feed and irrigation.

Nevertheless, notwithstanding the limitations of the data and restrictive assumptions, useful conclusion can be drawn: smaller and less intense farms are likely to be more flexible with production given increase in water cost *or* increased expected payout. Indeed increase in payout is likely to increase demand for water, where available, for farms that have the untapped ability to increase DM yields due to irrigation.

In conclusion, rather than relying on tools such water intake restrictions and arbitrary distribution of water resource consents, theoretical rationale suggests that a pricing mechanism can be a viable alternative for water demand management in the face of scarcity. It is hoped that this study adds perspective to discussion on the topic.

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