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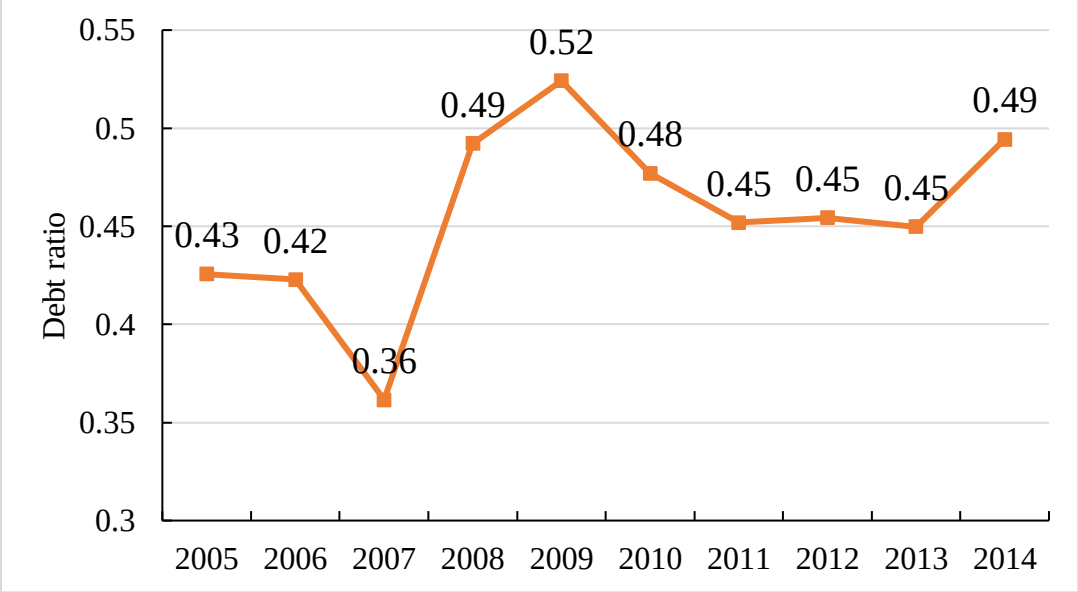

Supplemental Figure S1. The change of debt ratio over time (2005-2014)

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Supplemental Table S1. The characteristics of five dairy production systems in New Zealand

Systems [a]	Characteristics
System 1	*Self-contained – no imported feed* No supplement fed, except supplement harvested off the effective milking area and no grazing off the effective milking area by dry cows
System 2	*4 – 14% of the total feed imported* Feed imported, either as supplements to milking cows or grazing and supplements for dry cows
System 3	*10 – 20% of the total feed imported* Feed imported, both as supplements to extend lactation (typically autumn feed) and grazing and supplements for dry cows.
System 4	*20 – 30% of the total feed imported* Feed imported, both as supplements used at both ends of lactation and grazing and supplements for dry cows
System 5	*More than 30% of of the total feed imported* Feed imported for use all year, both supplements used throughout lactation and grazing and supplements for dry cows. Split calving is common in this system

Source: (DairyNZ, 2017)

[a] The five production systems are mainly categorized based on the timing, purpose and amount of imported feed used, and it is possible that a dairy farm may shift from one system to another system over time.

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Supplemental Table S2. Distribution of debt ratio in New Zealand by production systems

Systems	Mean debt ratio	Mean difference [a]	95% Confidence Interval	
System 1	0.415		0.396	0.435
System 2	0.436	0.021*	0.426	0.447
System 3	0.456	0.041***	0.448	0.465
System 4	0.479	0.063***	0.467	0.490
System 5	0.495	0.079***	0.474	0.515

[a] Mean difference refers to the difference of debt ratio between a higher system and pasture-based system 1.

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Supplemental Table S3. The impacts of Debt per kg milksolids on productivity and profitability: FE model estimates

Variables	Productivity	Profitability
Debt per kg MS (log)	-0.023*** (-10.67)	-0.126*** (-8.44)
Farm size (Base=Quartile 1)		0.000 (.)
Quartile 2	-0.042*** (-5.10)	0.046 (0.81)
Quartile 3	-0.056*** (-6.45)	0.089 (1.49)
Quartile 4	-0.104*** (-9.85)	0.121* (1.68)
Dairy farming systems (Base=System 1)		0.000 (.)
System 2	0.010 (1.46)	0.002 (0.05)
System 3	0.032*** (4.39)	-0.004 (-0.07)
System 4	0.049*** (6.11)	-0.052 (-0.95)
System 5	0.085*** (8.36)	-0.026 (-0.38)
Milk price (log)	-0.166*** (-11.72)	3.102*** (32.10)
Business type	-0.083*** (-6.60)	0.823*** (9.65)
Irrigation intensity	0.023*** (3.46)	0.030 (0.66)
Milking frequency	0.073*** (11.10)	0.143*** (3.16)
Cattle breeds	0.009* (1.70)	-0.017 (-0.48)
Stocking rate	0.263*** (45.61)	0.289*** (7.35)
Year dummies (Base=2005)		0.000 (.)
2006	0.029*** (5.76)	-0.167*** (-4.83)
2007	0.045*** (4.75)	-0.638*** (-9.91)
2008	0.036*** (5.76)	-0.958*** (-22.19)
2009	0.037*** (5.01)	-0.599*** (-11.82)
2010	0.097*** (10.34)	-0.651*** (-10.15)
2011	0.165*** (18.99)	-0.562*** (-9.47)
2012	0.112*** (13.74)	-0.818*** (-14.71)
2013	0.202*** (19.74)	-0.695*** (-9.98)
2014	0.179*** (22.93)	-0.729*** (-13.72)
Constant	6.389*** (201.87)	1.525*** (7.07)
Observations	7,636	7,636

Note: *t* statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

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Supplemental Table S4. Impact of debt ratio on technical efficiency of dairy farms in New Zealand

Production function: Dependent variable=log (dairy productivity)	
Labor expenses (log) [a]	0.048*** (7.27)
Stock expenses (log) [a]	0.135*** (21.02)
Feed expenses (log) [a]	0.097*** (31.78)
Overhead expenses (log) [a]	0.027*** (5.68)
Other expenses (log) [a]	0.076*** (15.80)
Farm size (log) [a]	0.012* (1.72)
Constant	4.826*** (68.09)
Technical inefficiency function	
Debt ratio (log)	0.004* (1.91)
Farm size	-0.004 (-1.05)
Farming systems	-0.020*** (-11.20)
Milk price (log)	0.304*** (35.10)
Business type	0.004 (0.58)
Irrigation intensity	-0.026*** (-10.76)
Milking frequency	-0.106*** (-19.41)
Cattle breeds	-0.011*** (-3.63)
Stocking rate	-0.248*** (-54.77)
Time trend	-0.003*** (-3.98)
Constant	0.825*** (28.14)
Usigma	-4.844*** (-42.86)
Vsigma	-4.864*** (-44.69)
Log likelihood	5161.596
Observations	7,636

Note: *t*-statistics in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01

[a] The input variable is measured at NZD/hectare

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Supplemental Table S5. Impact of debt ratio on return on assets

	Dependent variable= return on assets (%)		
Variable	(a) FE model	(b) RE model	(c) Pooled-OLS
Debt ratio (log)	-0.044*** (-6.77)	-0.017*** (-3.83)	-0.017*** (-3.83)
Farm size (Base=Quartile 1)			
Quartile 2	0.028 (1.24)	0.002 (0.21)	0.002 (0.21)
Quartile 3	0.024 (1.01)	0.010 (0.95)	0.010 (0.95)
Quartile 4	0.022 (0.77)	0.023** (1.97)	0.023** (1.97)
Dairy farming systems (Base=System 1)			
System 2	-0.082*** (-4.56)	-0.040*** (-3.08)	-0.040*** (-3.08)
System 3	-0.061*** (-3.11)	-0.039*** (-2.90)	-0.039*** (-2.90)
System 4	-0.075*** (-3.46)	-0.049*** (-3.34)	-0.049*** (-3.34)
System 5	-0.062** (-2.30)	-0.040** (-2.16)	-0.040** (-2.16)
Milk price (log)	0.344*** (9.09)	0.407*** (13.22)	0.407*** (13.22)
Business type	0.275*** (8.38)	0.392*** (18.93)	0.392*** (18.93)
Irrigation intensity	0.023 (1.28)	0.004 (0.59)	0.004 (0.59)
Milking frequency	0.000 (0.02)	0.018 (1.47)	0.018 (1.47)
Cattle breeds	0.005 (0.34)	0.014* (1.79)	0.014* (1.79)
Stocking rate	-0.037** (-2.37)	0.006 (0.82)	0.006 (0.82)
Year dummies (Base=2005)			
2006	-0.012 (-0.90)	-0.014 (-1.13)	-0.014 (-1.13)
2007	0.050** (1.98)	0.026 (1.25)	0.026 (1.25)
2008	-0.308*** (-18.17)	-0.319*** (-22.02)	-0.319*** (-22.02)
2009	-0.168*** (-8.44)	-0.186*** (-11.27)	-0.186*** (-11.27)
2010	-0.132*** (-5.24)	-0.151*** (-7.37)	-0.151*** (-7.37)
2011	-0.131*** (-5.59)	-0.140*** (-7.40)	-0.140*** (-7.40)
2012	-0.205*** (-9.35)	-0.216*** (-12.36)	-0.216*** (-12.36)
2013	-0.219*** (-8.01)	-0.240*** (-11.10)	-0.240*** (-11.10)
2014	-0.249*** (-11.90)	-0.259*** (-15.90)	-0.259*** (-15.90)
Constant	-0.306*** (-3.63)	-0.559*** (-9.82)	-0.559*** (-9.82)
F-test ($\mu_i = 0$)	F(2636, 4976) = 1.74; Pro>F=0.000		
Hausman test	Chi2(23)= 87.97; Pro>Chi2=0.000		
Observations	7,636	7,636	7,636

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Note: *t*-statistics in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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Supplemental Table S6. Impact of debt ratio changes over time on dairy productivity and profitability: FE model estimates

Variables	Productivity	Profitability
Debt ratio (log) * Dummy_2005	0.017*** (3.44)	-0.396*** (-12.55)
Debt ratio (log) * Dummy_2006	0.005 (1.03)	-0.269*** (-9.27)
Debt ratio (log) * Dummy_2007	0.032*** (9.04)	-0.090*** (-3.89)
Debt ratio (log) * Dummy_2008	0.021*** (4.51)	0.182*** (6.04)
Debt ratio (log) * Dummy_2009	0.030*** (7.04)	-0.065** (-2.33)
Debt ratio (log) * Dummy_2010	0.002 (0.58)	-0.079*** (-3.01)
Debt ratio (log) * Dummy_2011	-0.048*** (-12.86)	-0.136*** (-5.66)
Debt ratio (log) * Dummy_2012	-0.011*** (-3.26)	0.052** (2.29)
Debt ratio (log) * Dummy_2013	-0.058*** (-15.44)	-0.086*** (-3.56)
Debt ratio (log) * Dummy_2014	-0.059*** (-15.39)	0.000 (0.01)
Farm size (Base=Quartile 1)		
Quartile 2	-0.033*** (-3.65)	-0.002 (-0.04)
Quartile 3	-0.030*** (-3.18)	-0.013 (-0.21)
Quartile 4	-0.060*** (-5.31)	-0.045 (-0.62)
Dairy farming systems (Base=System 1)		
System 2	0.018** (2.46)	-0.018 (-0.38)
System 3	0.049*** (6.14)	-0.064 (-1.23)
System 4	0.073*** (8.32)	-0.124** (-2.20)
System 5	0.117*** (10.67)	-0.084 (-1.18)
Milk price (log)	-0.062*** (-7.08)	2.722*** (47.88)
Business type	-0.031*** (-2.65)	0.925*** (12.23)
Irrigation intensity	0.029*** (4.06)	0.031 (0.66)
Milking frequency	0.071*** (9.84)	0.160*** (3.42)
Cattle breeds	0.015** (2.52)	-0.040 (-1.08)
Stocking rate	0.276*** (43.96)	0.258*** (6.35)
Constant	6.154*** (221.61)	1.387*** (7.72)
Observations	7,636	7,636

Note: *t* statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

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Supplemental Table S7. Impact of debt ratio on dairy productivity and profitability (farms with more than 4-years observations: FE model estimates

Variables	Productivity	Profitability
Debt ratio (log)	-0.004 (-1.32)	-0.054** (-2.03)
Farm size (Base=Quartile 1)		
Quartile 2	-0.050*** (-4.08)	0.060 (0.63)
Quartile 3	-0.089*** (-6.14)	-0.101 (-0.90)
Quartile 4	-0.132*** (-7.63)	0.056 (0.41)
Dairy farming systems (Base=System 1)		
System 2	0.000 (0.02)	-0.087 (-1.09)
System 3	0.016 (1.41)	-0.138 (-1.59)
System 4	0.019 (1.59)	-0.205** (-2.20)
System 5	0.043*** (2.85)	-0.286** (-2.43)
Milk price (log)	-0.159*** (-8.25)	3.243*** (21.69)
Business type	-0.056*** (-2.97)	0.923*** (6.27)
Irrigation intensity	0.017* (1.78)	-0.021 (-0.28)
Milking frequency	0.055*** (5.43)	0.103 (1.32)
Cattle breeds	0.013* (1.75)	0.008 (0.13)
Stocking rate	0.264*** (31.08)	0.220*** (3.34)
Year dummies (Base=2005)		
2006	0.031*** (4.55)	-0.240*** (-4.54)
2007	0.040*** (3.03)	-0.747*** (-7.36)
2008	0.031*** (3.31)	-1.114*** (-15.25)
2009	0.032*** (2.98)	-0.688*** (-8.16)
2010	0.083*** (6.15)	-0.724*** (-6.88)
2011	0.152*** (12.08)	-0.660*** (-6.76)
2012	0.103*** (8.69)	-0.920*** (-9.96)
2013	0.195*** (13.37)	-0.808*** (-7.12)
2014	0.176*** (15.17)	-0.810*** (-9.00)
Constant	6.364*** (138.68)	1.385*** (3.88)
Observations	4,428	4,428

Note: *t* statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

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Supplemental Table S8. Impact of debt ratio on dairy productivity and profitability (farms with 10-years observations): FE model estimates

Variables	Productivity	Profitability
Debt ratio (log)	-0.027 (-1.33)	-0.023 (-0.18)
Farm size (Base=Quartile 1)		
Quartile 2	0.046 (0.87)	0.015 (0.04)
Quartile 3	0.062 (1.18)	-0.017 (-0.05)
Quartile 4	0.121 (1.29)	0.287 (0.49)
Dairy farming systems (Base=System 1)		
System 2	0.021 (0.74)	0.085 (0.47)
System 3	0.062** (2.03)	0.101 (0.53)
System 4	0.157*** (4.58)	0.304 (1.41)
System 5	0.205*** (5.47)	0.307 (1.30)
Milk price (log)	-0.252*** (-3.05)	3.492*** (6.71)
Irrigation intensity	0.125*** (2.81)	0.453 (1.62)
Milking frequency	0.160*** (5.30)	0.470** (2.48)
Cattle breeds	-0.068* (-1.69)	0.089 (0.35)
Stocking rate	0.140*** (3.85)	0.227 (0.99)
Year dummies (Base=2005)		
2006	0.022 (1.05)	-0.043 (-0.33)
2007	0.046 (0.89)	-1.107*** (-3.37)
2008	0.020 (0.82)	-1.199*** (-7.69)
2009	0.015 (0.40)	-0.979*** (-4.07)
2010	0.085* (1.68)	-1.156*** (-3.61)
2011	0.171*** (3.83)	-0.894*** (-3.20)
2012	0.103** (2.47)	-1.044*** (-3.98)
2013	0.188*** (3.46)	-1.144*** (-3.35)
2014	0.153*** (4.07)	-1.015*** (-4.31)
Constant	6.635*** (36.70)	0.544 (0.48)
Observations	250	250

Note: *t* statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The business type variable has been dropped in the estimation because only 10 samples of owner operations were left in the used dataset.