Annex A. Modelling net margin with an optimisation model

A.1. Model specification and variables

Objective function: maximise benefits (max Z) as the difference of gross margin minus variable costs with some restrictions, specified for each system and location (see below).

$$Z = X_1 - 0.44\,X_2 - 0.66\,X_3 - 0.65\,X_4 - 0.85\,X_5 - 0.64\,X_6 - 16.44\,X_7 - 9.87\,X_8 - 20\,X_9 - 12\,X_{10} - 15\,X_{11} + 0\,X_{12} - 0.42\,X_{13} + 0.42\,X_{14} + 0\,X_{15} + 0\,X_{16} + 84\,X_{17} - 0.90\,X_{18} - 0.55\,X_{19} - 15\,X_{20} + 0\,X_{21} - 4.62\,X_{22} - 0.65\,X_{23} - 0.85\,X_{24} - 0.64\,X_{25} - 20\,X_{26} - 15\,X_{27} - 15X_{28} - 15\,X_{29} - 15\,X_{30} \quad \text{Eq (A.1)}$$

Table A.1. Model coefficients and data variables, values and sources

Model variables	Model variables	Units	Model coefficients	Model coefficients	Value of model coefficients
	POTATO VARIABLES				
X1	Potato farming hectares	ha	A1	Net benefit per average farm of 2.41 ha	6353 USD
X2	Household consumption	kg/household	A2	Price per unit	0.44 USD kg^{-1}
X3	Amount of seed	kg	A3	Price per unit	0.66 USD kg^{-1}
X4	Amount of fertilizer (N) urea	kg	A4	Price per unit	0.65 USD kg^{-1}
X5	Amount of fertilizer (P2O5) DAP (18-46-00)	kg	A5	Price per unit	0.85 USD kg^{-1}
X6	Amount of Fertilizer (K2O) (muriate of potash)	kg	A6	Price per unit	0.64 USD kg^{-1}
X7	Amount of fungicide	kg	A7	Price per unit	16.44 USD kg^{-1}
X8	Amount of insecticide	kg	A8	Price per unit	9.87 USD kg^{-1}
X9	Amount of hours of renting machinery for tillage	hours	A9	Price per unit	20 USD $hour^{-1}$
X10	Amount of foliar fertiliser	kg	A10	Price per unit	12 USD kg^{-1}
X11	Household labour	days	A11	Price per unit	15 USD day^{-1}
	Milk production variables				
X12	Number of cows	number	A12	Assumption: the cows are not sold	0
X13	Milk for self-consumption	kg	A13	Price per unit	0.42 USD kg^{-1}
X14	Milk for sale	kg	A14	Price per unit	0.42 USD kg^{-1}
X15	Birth of calves	number	A15	Assumption: the calves are not sold	0 USD $animal^{-1}$
X16	Calves remaining on the farm	number	A16	Assumption: the calves are not sold	0 USD $animal^{-1}$
X17	Calves sold	number	A17	Price per calves	84 USD $animal^{-1}$
X18	Amount of mineral salt		A18	Price per unit	0.90 USD kg^{-1}
X19	Amount of supplemental feeding	kg	A19	Price per unit	0.55 USD kg^{-1}
X20	Number of days of household labour	days	A20	Price per unit	15 USD day^{-1}
	PASTURE VARIABLES				
X21	Pasture area	ha	A21	Assumption: the pasture is not sold	0
X22	Production of pasture seed	kg	A22	Price per unit	4.62 USD kg^{-1}
X23	Amount of nitrogen fertiliser	kg	A23	Price per unit	0.65 USD kg^{-1}
X24	Amount of phosphorus fertiliser	kg	A24	Price per unit	0.85 USD kg^{-1}
X25	Amount of potassium fertiliser	kg	A25	Price per unit	0.64 USD kg^{-1}
X26	Hours of renting machinery for soil preparation	hours	A26	Price per unit	20 USD $hour^{-1}$
X27	Household labour	days	A27	Price per unit	15 USD kg^{-1}
	Hired labour				
X28	Hired labour for potato production	days	A28	Price per unit	15 USD day^{-1}
X29	Hired labour for milk production	days	A29	Price per unit	15 USD day^{-1}
X30	Hired labour for pasture production	days	A30	Price per unit	15 USD day^{-1}

Source of data: Barrera *et al.* (2004, 2010); INIAP (2013); INEC (2016)

Table A.2. Model restrictions for potato production

Restrictions			Definition
Potato			
X1	≤	2.41 ha	Hectares must be less than or equal to 2.41
14439 X1		1200	14,439 kg ha^{-1} (potato yield) should be greater than or equal to 1,200 kg (quantity for self-consumption)
X2	≥	1200	self-consumption must be greater than or equal to 1200 kg yr^{-1}
X3 – 1144.3 X1	≥	0	Seed must be greater than or equal to 1,144.3 kg ha^{-1}
X4 – 91.6 X1		0	Fertilizer (N) must be greater than or equal to 91.6 kg/ha urea
X5 –906X1	≥	0	Fertilizer (P_2O_5) must be greater than or equal to 906 kg ha^{-1} of DAP (18-46-00)
X6 – 303 X1	≥	0	Fertilizer (K_2O) must be greater than or equal to 303 kg ha^{-1} of muriate of potash
X7 – 15 X1	≥	0	Fungicides must be greater than or equal to 15 kg ha^{-1}
X8 –3.5X1	≥	0	Insecticides must be greater than or equal to 3.5 kg ha^{-1}
X9 – 8 X1	≥	0	Tractor hours must be greater than or equal to 8 hours ha^{-1}
X10 - 16 X1	≥	0	Foliar fertilizer must be greater than or equal to 16 kg ha^{-1} (4 kg ha^{-1} $application^{-1}$
X30 + X11 – 128 X1	≥	0	Hired labour plus family labour must be greater than or equal to 108 days ha^{-1} yr^{-1}
Milk production			
X12	≤	7.66	Hectares of pasture must be less than or equal to 7.66
X13	≥	730	self-consumption must be greater than or equal to 730 kg yr^{-1}
X13 + X14 - 3650 X12	≤	0	Milk consumption per household plus milk sold must be less than or equal to 3,650 kg yr^{-1}
X15 - 0.70 X12	≤	0	Births of calves must be less than or equal to 70% of birth of cows
X16 - 0.5 X15	≥	0	Number of calves that stay with the farmer must be greater than or equal to 50% of animals born
X17 - 0.5 X15	≤	0	Number of calves sold must be less than or equal to 50% of the animals born
X18 - 62.05 X12 - 32.85X16	≥	0	Mineral salt used should be greater than or equal to 62.05 kg (cows) plus 32.85 kg (calf)
X19 - 313.9 X12 - 146 X16	≥	0	Supplemental feeding used should be greater than or equal to 313.9 kg (cows) plus 146 kg (calf)
X31 + X20 - 15 X12	≥	0	Hired labour plus family labour must be greater than or equal to 15 days yr^{-1}
Pasture			
X22 - 44X12	≥	0	Seed must be greater than or equal to 44 kg/ha
X23 – 115 X12	≥	0	Fertilizer (N) must be greater than or equal to 115 kg ha^{-1}
X24 - 261 X12	≥	0	Fertilizer (P_2O_5) must be greater than or equal to 261 kg ha^{-1}
X25 - 100 X12	≥	0	Fertilizer (K_2O) must be greater than or equal to 100 kg ha^{-1}
X26 – 3.2 X12	≥	0	Tractor hours must be greater than or equal to 3.2 hours ha^{-1}
X32 + X27 – 11X12	≥	0	Hired labour plus family labour must be greater than or equal to 11 days ha^{-1} yr^{-1}
General restrictions			
X1 + X12	≤	10.07	Area of potatoes plus pasture must be less than or equal to 10.07 has
X11 + X20 + X27	≤	1460	Family labour for potatoes, Milk production and pasture must be less than or equal to 1460 days ha^{-1} (considering 4 people per family)

Source of data: Rueda (2002); Zarate (2002)