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Food demand to 2050: Opportunities for Australian agriculture–Algebraic description of agrifood model

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The ABARES agrifood model

The purpose of this technical annex is to provide an algebraic description of the ABARES agrifood model. ABARES used this model to create long-term projections of world agrifood demand. The projections and scope of the model are described in a paper presented at the 2012 Outlook conference in Canberra (Linehan et al. 2012).

The ABARES agrifood model is a multi-product, multi-region partial equilibrium model of key demand and supply interactions between world agricultural commodities used for food, animal feed or other purposes.

Commodity and region coverage are given in tables 2 and 3. Chapter 1 outlines key features of the model, while Chapter 2 discusses its implementation. Chapters 3 and 4 provide a full description of the model. Data sources are noted in Chapter 5.

1 Model overview

In the ABARES agrifood model the dynamics are recursive, markets are perfectly competitive, and each commodity produced and/or consumed across regions is homogeneous. In a recursive dynamic framework, agents are myopic (that is, make decisions on the basis of current conditions) and base their annual decisions on assumed economic conditions.

Annual results change over time in the model with exogenous changes in demand and supply conditions. When markets are competitive, agents treat input and output prices as given. In the model, annual regional demand and supply decisions are made by representative producers and consumers of agrifood products to maximise each of their annual net benefits.

When a product is homogeneous, simultaneous exporting to the world market and importing from the world market of the same good at the same time and place will not occur. The model captures this feature in the prices and trade block. In particular, world price adjusts to balance aggregate demand with aggregate supply from each region and for each traded agrifood good. A unit transport cost to and from the world market is specified to distinguish export from import parity price in the absence of government price interventions. Producer and consumer support estimates are used in the model to capture government agrifood support policies.

Using a mixed complementarity problem (MCP) framework for the model, a region switches between exporter to autarky to importer depending on benefit and cost conditions. Domestic product price is bounded from above by the import parity price and from below by the export parity price. If the domestic unit cost of production is lower than the export parity price, then exports increase until marginal net benefits are zero.

Exports are the excess of local supply over local demand. If the import parity price is lower than the domestic unit cost of production, then imports increase until marginal net benefits are zero. Imports are the excess of local demand over local supply. Otherwise, it is not profitable to trade and the local price lies between the export and import parity price. The local price clears local demand with local supply in this case.

It is not practical to disaggregate all commodities to a level that always avoids simultaneous exporting and importing of the same aggregated good in the base year data. The approach used here is to calibrate the base year model value of exports (imports) to the recorded value of net exports (imports) for a net exporter (importer). See the appendix of Linehan et al. (2012) for further discussion.

The MCP framework also allows key activities, such as production, to switch on or off in response to economic conditions. For example, using the MCP framework, production of a particular good occurs if conditions are profitable, and the level of production occurs where marginal net benefits are eliminated. If marginal net benefit is always negative, then production is unprofitable and will not occur.

The discussion in the following two subsections is organised around the remaining blocks of the model. These are the main supply and related land market balances, and demand features in the subsequent algebraic description of the model.

Agrifood supply and land market balances

In each region, supply decisions are modelled separately for various crops and livestock products, fish, fish reduction to meal and oil concentrate, the crush of key oilseeds to meal and oil, and the production of generic feed mix concentrate for livestock. The model's algebraic description starts with this production block structure. Relevant model variables are given in Table 5 and defined over sets in Table 1.

From the land market balance equations, land use is a key linkage between crop and livestock production activities in the model. Regional crop enterprises compete for crop land; grazing enterprises compete for both pasture land and crop land, and an endogenous price premium is charged for crop land over pasture land use.

In each case, land supply for crop land or pasture land is responsive to the rental price of land to account for land conversion from other uses in response to profit opportunities. Agricultural land use expansion in each case has a finite limit and this is imposed as an additional model constraint which, when binding via the associated shadow tax, adds to the marginal cost of land use expansion sufficiently to make it unprofitable.

Differences in regional intensity of land use reflect relative land rental prices. Local livestock product enterprises compete indirectly with local crops for crop land through feed demand.

In the agrifood model, crop and livestock product supply are modelled in similar ways, with livestock products requiring an additional input to account for animal feed. Land and feed use are modelled in fixed proportions to livestock product output (that is, a Leontief technology is used). The unit cost of other inputs to production increases with production, allowing some land use diversification. Like adding a sector specific factor of production, the increasing unit cost of production limits the expansion of the specific enterprise, allowing competing agricultural land use to expand to some extent, dependent on relevant parameter values.

Exogenous technical advance is assumed to improve land and feed input–output coefficients and unit operating cost of production. Selected technical change assumptions can be found in tables 6 to 10.

As currently modelled, the intensity of land use by crop and livestock farming enterprises is exogenous and differs across regions, reflecting history and technical advance trends. Typically, regions with relatively low land rental prices use extensive production technologies (high land input–output coefficients) while regions with relatively high land rental prices use intensive production technologies (low land input–output coefficients.) In this context, competition in production between regions reflects competition between extensive and intensive production techniques, other things being equal.

Given the importance of fish product as a food item in some regions, the supply of fish product was also endogenously modelled. High and low value capture fisheries are distinguished in each region of the model and these are subject to exogenous production quotas. Both high and low value fish types are assumed to be perfect substitutes in making fish meal and oil product. An endogenous price premium is incorporated in the model because high and low value fish are imperfectly substitutable as human food.

The behaviour of key oilseed crush sectors is modelled using a Cobb–Douglas transformation function in which oilseed is the input and meal and oil the outputs.

Data limitations in relation to feed meant that a simple approach was used to model livestock product feed production and use. In particular, a generic feed mix was created for each region's own use. Demand for each raw or processed ingredient conforms to a constant elasticity of substitution (ces) production relationship. Total feed mix production is the sum of the input–output requirements by each livestock product type.

Agrifood demand

Aggregate demand for a product in a region is the sum of food and feed demand and demand in other uses. The latter includes biofuel production, where demand is represented as an exogenous share of total domestic demand. In each region, aggregate demand for each good plus potential exports balances aggregate regional supply plus potential imports.

All terms in a commodity balance are measured in primary product equivalent. For example, milk product exports represent the primary product equivalent of dairy exports.

Domestic food demand is modelled in two steps. First, demands for food groups are chosen by the representative consumer according to a log linear specification in exogenous real income and endogenous own and substitute prices. Food groups include meat, dairy products, fish, cereals, vegetables and fruit, vegetable oils and other food items.

At the second level, a constant elasticity of substitution functional relationship is imposed between commodities within a group. Exogenous taste changes by product are included here; by assumption these may be used to moderate or amplify outward shifts in demand over time from per capita income and population growth.

2 Model implementation

The ABARES model was implemented in the General Algebraic Modeling System (GAMS) in scaled form using the PATH solver (Rutherford 1995). The algebraic description adopts GAMS-like notation.

Chapter 3 contains definitions of the variables and parameters of the model, and the main sets of commodities and activities over which they are defined. The model is specified as a set of competitive equilibrium conditions on prices and volumes, with inequalities as appropriate. The name of each equation identifies the variable it determines. This correspondence is only necessary for equations with inequalities, to enable GAMS to infer complementary slackness conditions.

The convention is followed that variables for which index ranges are not meaningful are fixed to zero prior to solving. Where equations include base year values of endogenous variables, these are exogenous and the convention is that a zero appended to the variable name.

All prices are real, expressed in US dollars of the base year in 2007. Quantity data are in millions of tonnes.

Data sources to calibrate the base year and run the recursive model are discussed in Chapter 5.

3 Model notation

Table 1 Sets used in the agrifood model

t	years	/2007,..., 2050/
i	commodities	/bef,pok,she,pul,egg,mlk,whe,rce,mze,oce,pot,spo,ort, soy,soyml, soyol,rap,rapml,rapol,sun,sunml, sunol,ovegml, ovegol,veg,frt,sugr,fishvcs,fislvcs,fisaqus,fishvd,fislvd,fimo/
ic(i)	crop commodities	/whe,rce,mze,oce,pot,spo,ort,soy, rap,sun,ovegml,ovegol, veg,frt, sugr/
ilc(ic)	crop commodities using general crop land	/whe,rce,mze,oce,pot,spo,ort,soy,rap,sun,veg,frt, sugr/
il(i)	livestock product commodities	/bef,pok,she,pul,egg,mlk/
ilg(il)	livestock commodities using grazing land	/bef,she/
ifs(i)	fish types of supply	/fishvcs,fislvcs,fisaqus/
ifsc(ifs)	capture fish technologies	/fishvcs,fislvcs/
ifsa(ifs)	aquaculture technology	/fisaqus/
ifishs(ifs)	high value fisheries	/fishvcs,fisaqus/
ifisls(ifs)	low value fisheries	/fislvcs/
ifisd(i)	fish demand types	/fishvd,fislvd/
ifimo(i)	fish meal and oil concentrate from reduction	/fimo/
icruip(i)	fully specified oilseed crush complex inputs	/soy,rap,sun/
icruop(i)	fully specified oilseed crush complex outputs	/soyml,soyol,rapml,rapol,sunml,sunol/
icruopml(i)	fully specified oilseed crush complex meal outputs	/soyml,rapml,sunml/
icruopol(i)	fully specified oilseed crush complex oil outputs	/soyol,rapol,sunol/
ifd(i)	commodities for generic livestock feed mix	/whe,mze,oce,pot,spo,ort,soyml,rapml,sunml,ovegml/
ifdt(i)	commodities used to make generic feed or to feed aquaculture	/whe,mze,oce,pot,spo,ort,soyml,rapml,sunml,ovegml, fimo/
ifdd(ifdt)	commodities for generic livestock feed mix	/whe,mze,oce,pot,spo,ort,soyml,rapml,sunml,ovegml/
ifimod(ifdt)	fish and meal concentrate from reduction	/fimo/
Ifisrd(i)	fish usable for reduction	/fishvd,fislvd/
ifo(i)	food commodities	/bef,pok,she,pul,egg,mlk,whe,rce,mze,oce,pot,spo,ort, soy,soyol,rap,rapol,sun,sunol,ovegol,veg,frt, sugr,fishvd,fislvd/
ims(i)	commodities with other miscellaneous uses (includes feed that isn't modelled and biofuels)	/bef,pok,she,pul,egg,mlk,whe,rce,mze,oce,pot,spo,ort, soy,soyol,rap,rapol,sun,sunol,ovegol,veg,frt, sugr,fishvd,fislvd/
iagg	groups of food commodities	/fishg,meatg,mlkg,cerlsg,vgfrt,oilsg,ofood/
n	regions	/usa,can,mex,brz,arg,rame,jpn,kor,chn,reas,ceas, ind,pak,bgd,lka,rsas,idn,mys,mmr,phl,tha,vnm,rsea,weas,tur, eu15,eeu,seu,reu,aus,roce,egy,nga,rsa, rnaf,rmwf,rsef/
alias(nn,n),(jagg,iagg)		

Note: It is necessary to define some subsets more than once, depending on the equation structure. Full names of commodities and regions used in the model are explained in tables 2 and 3.

Table 2 Commodities in the agrifood model

Code	Name	Aggregated grouping
bef	Beef a b	Meat
pok	Pig meat	Meat
she	Sheep meat c	Meat
pul	Poultry	Meat
egg	Eggs	Other food
mlk	Dairy products d	Dairy products
whe	Wheat e	Cereals
rce	Rice f	Cereals
mze	Maize	Cereals
oce	Other cereals g	Cereals
pot	Potatoes	Vegetables and fruit
spo	Sweet potatoes h	Vegetables and fruit
ort	Other roots	Vegetables and fruit
soy	Soybeans	Other food
soyml	Soybean meal	Vegetable meals
soyol	Soybean oil	Vegetable oils
rap	Rapeseed	Other food
rapml	Rapeseed meal	Vegetable meals
rapol	Rapeseed oil	Vegetable oils
sun	Sunflower seed	Other food
sunml	Sunflower meal	Vegetable meals
sunol	Sunflower oil	Vegetable oils
ovegml	Other vegetable meals	Vegetable meals
ovegol	Other vegetable oils	Vegetable oils
veg	Vegetables	Vegetables and fruit
frt	Fruit i	Vegetables and fruit
sugr	Sugar j	Other food
fishvcs	Fish high value capture k	Fish
fislvcs	Fish low value capture k	Fish
fisaqus	Fish aquaculture k	Fish
fishvd	Fish high value demand k	Fish
fislvd	Fish low value demand k	Fish
fimo	Fish meal and oil concentrate	Fish meal and oil concentrate

a Includes meat equivalent of live animal trade. b All bovine meat, including buffalo. c Includes goat meat. d Milk and milk equivalent of dairy products. e Includes wheat equivalent of flour and bakery products. f Milled equivalent. g Includes barley equivalent of malt, excludes beer. h Includes yams. i Excludes wine. j Raw sugar equivalent. k Includes seafood products.

Note: Commodities in the agrifood model are based on commodity definitions used in the Food and Agriculture Organization's food balance sheets (FAO 2011).

Table 3 Regions in the agrifood model

Code	Name	Code	Name
usa	United States	phl	Philippines
can	Canada	tha	Thailand
mex	Mexico	vnm	Vietnam
brz	Brazil	rsea	Rest of South East Asia d
arg	Argentina	weas	West Asia e
rame	Rest of America	tur	Turkey
jpn	Japan	eu15	European Union 15 f
kor	Republic of Korea	eeu	Eastern Europe g
chn	China	seu	Southern Europe h
reas	Rest of East Asia a	reu	Rest of Europe i
ceas	Central Asia b	aus	Australia
ind	India	roce	Rest of Oceania j
pak	Pakistan	egy	Egypt
bgd	Bangladesh	rnaf	Rest of North Africa
lka	Sri Lanka	nga	Nigeria
rsas	Rest of South Asia c	rmwf	Rest of Middle and Western Africa
idn	Indonesia	rsa	Republic of South Africa
mys	Malaysia	rsef	Rest of Southern and Eastern Africa
mmr	Myanmar		

Note: Regions used in the ABARES agrifood model are based on United Nations geographical regions (United Nations 2011). a China (Hong Kong) Special Administrative Region, China (Macao) Special Administrative Region, Democratic People's Republic of Korea and Mongolia. b Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. c Afghanistan, Bhutan, Islamic Republic of Iran, Maldives and Nepal. d Brunei Darussalam, Cambodia, Lao People's Democratic Republic, Singapore and Timor–Leste. e Armenia, Azerbajan, Bahrain, Cyprus, Georgia, Iraq, Israel, Jordan, Kuwait, Lebanon, Occupied Palestinian Territory, Oman, Saudi Arabia, Syrian Arab Republic and United Arab Emirates. f Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. g Belarus, Bulgaria, Czech Republic, Hungary, Poland, Republic of Moldova, Romania, Russian Federation, Slovakia and Ukraine. h Albania, Andorra, Bosnia and Herzegovina, Croatia, Gibraltar, Holy See, Malta, Montenegro, San Marino, Serbia, Slovenia, and The former Yugoslav Republic of Macedonia. i Åland Islands, Channel Islands, Estonia, Faeroe Islands, Guernsey, Iceland, Isle of Man, Jersey, Latvia, Lithuania, Norway, Sark, Svalbard and Jan Mayen Islands, Lichtenstein, Monaco and Switzerland. j Predominantly New Zealand.

Table 4 Parameters used in the agrifood model

Dummy variable mappings	
dvcrush(icruip,i)	dummy mapping crush input to output
dvmkfis(ifs,i)	dummy mapping fish supplies to fish demand types
dvfdagg(ifo,iagg)	dummy mapping food commodity to food group
Agricultural land limits	
lndscmax(n)	fixed upper limit on feasible crop land supply
lndspmax(n)	fixed upper limit on feasible pasture land supply
Behavioural elasticities	
esc(n,ic)	unit (price) operating cost elasticity of crop supply
esl(n,il)	unit (price) operating cost elasticity of livestock product supply
esf(n,ifs)	unit (price) operating cost elasticity of fish supply
esfrd(n)	unit (price)operating cost elasticity of fish throughput for reduction
escru(icruip,n)	unit (price) operating cost elasticity of oilseed throughput for crush complex
sigmamx(n)	ces elasticity of substitution between inputs in livestock feed mix
eslndc(n)	own price elasticity of supply of crop land
eslndp(n)	own price elasticity of supply of pasture land
edfoincagg(iagg,n)	income elasticity of demand for food type
edfopagg(iagg,jagg,n)	own and cross-price elasticity of demand for food type
sigmafo(n,iagg)	ces elasticity of substitution between foods in food type
Behavioural input–output and output–input coefficients	
iolndc(t,n,ic)	input of land per unit crop output
iolndl(t,n,il)	input of land per unit livestock product output
iofdaq(t,n)	input of fimo per unit output of fish production in aquaculture
opipfrd(t,n,ifisd)	output of fimo per unit input of fish for reduction
iofdmx(t,n,il)	input of feed mix per unit output of livestock product
Exogenous technical change terms	
tcuopcci(t,n,ic)	index for exogenous trend in uopcc
tcuopcli(t,n,il)	index for exogenous trend in uopcl
tcuopcfi(t,n,ifs)	index for exogenous trend in uopcf
tcuopcfrdi(t,n)	index for exogenous trend in uopcfrd
tcuopccrui(t,n,icruip)	index for exogenous trend in uopccru
Exogenous environment	
gafi(t,n,ifsc)	index for exogenous trend in sustainable fish supply
ginci(t,n)	real income index
gtastesubi(t,n,ifo)	taste shifter index for food demand
shms(t,n,i)	share of miscellaneous other demands in total demand (fraction)
pse(t,n,i)	*ad valorem* producer support estimate (fraction)
cse(t,n,i)	*ad valorem* consumer support estimate (fraction)
tc(t,n,i)	unit transport cost to and from the world market

Note: Dummies are 1 for relevant cases and 0 elsewhere. Indexes are unity in base year 2007.

Table 5 Positive variables used in the agrifood model

Production of crops	
qsc(t,n,i)	crop output
uopcc(t,n,i)	unit operating cost of crop supply
lnddc(t,n,i)	land use for crop
Production of livestock products	
qsl(t,n,i)	livestock product output
uopcl(t,n,i)	unit operating cost of livestock product supply
plndg(t,n,i)	rental price of land used in livestock product output
lnddgc(t,n,i)	use of crop land by grazing industry
lnddgp(t,n,i)	use of pasture land by grazing industry
Production of fish	
qsf(t,n,i)	production of fish
uopcf(t,n,i)	unit operating cost of fish supply
pren(t,n,i)	rental price on fish quota
qdfimoaq(t,n)	use of fish meal and oil concentrate in aquaculture
Production of fish meal and oil concentrate	
qdfrd(t,n,i)	fish throughput for reduction
uopcfrd(t,n)	unit operating cost of fish throughput for reduction
qdfrdtot(t,n)	total fish throughput for reduction
qsfimo(t,n)	fish meal and oil production
Production of oilseed meals and oils	
qdcru(t,n,i)	oilseed crush throughput
pdcrustar(t,n,i)	price of Cobb–Douglas complex output
uopccru(t,n,i)	unit operating cost of crush throughput
qscrml(t,n,i)	oilseed crush meal output
qscrol(t,n,i)	oilseed crush oil output
Production of feed mix concentrate for livestock	
pdfdmx(t,n)	price of generic feed mix
qfdmxact(t,n)	generic feed mix produced
qdfdanl(t,n,il)	generic feed mix used by livestock type
qdfdfmx(t,n,i)	use of feed for production of generic mix
Land market balances and total production by commodity	
plndc(t,n)	crop land rental price
plndp(t,n)	pasture land rental price
plndctax(t,n)	shadow tax on feasible land available for crop land
plndptax(t,n)	shadow tax on feasible land available for pasture land
lndsc(t,n)	crop land supply
lndsp(t,n)	pasture land supply
Total local production	
qstot(t,n,i)	total local production by commodity
Demand for food, feed and other uses	
qdfoagg(t,n,iagg)	food aggregator quantity
pdfoagg(t,n,iagg)	food aggregator price
qdfo(t,n,i)	food consumption
qdfd(t,n,i)	feed consumption
qdms(t,n,i)	miscellaneous other consumption
qdtot(t,n,i)	total local consumption by commodity
Prices and trade	
ps(t,n,i)	producer price
pexptfob(t,n,i)	export parity price
pd(t,n,i)	consumer price
pimptcif(t,n,i)	import parity price
pg(t,n,i)	local price
expt(t,n,i)	exports
impt(t,n,i)	imports
pw(t,i)	world price

Table 6 Growth of input of land per unit crop output (iolndc)

				iolndc			
Region	whe	rce	mze	oce	pot	spo	ort
	%	%	%	%	%	%	%
usa	−0.498	−0.498	−0.498	−0.498	−0.498	−0.498	−1.888
can	−0.850		−0.742	−0.893	−1.072		
mex	−0.498	−1.256	−1.565	−0.498	−1.153	−0.535	−1.888
brz	−0.953	−1.310	−1.431	−1.437	−1.223	−1.237	−1.888
arg	−0.498	−0.982	−0.983	−0.498	−1.142	−1.091	−2.141
rame	−0.599	−1.158	−1.769	−1.437	−1.719	−1.642	−1.996
jpn	−0.498	−0.999		−1.437	−1.033	−0.498	−1.888
kor	−0.498	−1.021	−1.248	−1.437	−1.131	−1.003	
chn	−0.498	−1.016	−1.217	−1.437	−1.590	−0.508	−1.888
reas	−1.188	−2.141	−1.646	−1.437	−1.863	−0.857	
ceas	−1.128	−1.456	−1.235	−1.437	−1.517		
ind	−0.498	−1.418	−1.861	−1.437	−1.494	−1.398	−1.888
pak	−0.498	−1.413	−1.509	−1.437	−1.368	−1.212	−1.888
bgd	−1.090	−1.267	−1.131	−1.437	−1.570	−1.369	
lka	−0.498	−1.309	−2.249	−1.437	−1.596	−1.510	−2.199
rsas	−1.025	−1.466	−1.511	−1.992	−1.372		−2.800
idn		−1.179	−1.457		−1.510	−1.257	−1.888
mys		−1.367	−1.256	−1.437		−1.023	−1.915
mmr	−1.176	−1.293	−1.548	−1.437	−1.592	−1.586	−1.888
phl		−1.315	−1.776		−1.573	−1.912	−2.421
tha	−1.452	−1.489	−1.403	−1.437	−1.527		−1.888
vnm		−1.146	−1.403	−1.437	−1.826	−1.443	−1.888
rsea		−1.546	−1.471		−2.821	−1.713	−1.888
weas	−0.803	−1.449	−1.608	−1.760	−1.379	−0.498	−1.888
tur	−1.020	−0.863	−1.061	−1.092	−1.136		
eu15	−0.498	−0.936	−0.498	−0.498	−0.861	−1.203	−1.888
eeu	−0.825	−1.201	−1.628	−1.124	−1.597		
seu	−0.498	−1.038	−1.458	−0.858	−1.833		
reu	−1.090	−1.038	−0.637	−1.302	−1.861		−1.888
aus	−1.609	−0.498	−1.249	−1.326	−1.013	−0.498	
roce	−0.498	−1.589	−0.597	−0.498	−0.658	−1.575	−2.338
egy	−0.498	−0.498	−0.871	−1.437	−1.185	−0.498	−1.888
nga	−1.137	−2.351	−2.210	−1.436	−2.913	−1.472	−2.032
rsa	−0.498	−1.474	−1.687	−1.088	−1.033	−2.381	−2.465
rnaf	−1.405	−1.127	−2.913	−2.003	−1.345	−2.658	−2.913
rmwf	−1.119	−2.039	−2.736	−2.244	−2.599	−1.391	−2.360
rsef	−1.153	−1.723	−2.361	−1.714	−2.091	−1.808	−2.465
usa	−1.888	−0.498	−0.880	−0.498	−0.498	−0.498	−0.498
can		−0.956	−0.880	−0.596	−1.031	−1.339	−1.015
mex	−1.888	−1.269	−1.516	−1.027	−1.173	−1.158	−0.498
brz	−1.888	−0.498	−1.329	−0.750	−1.105	−1.049	−0.498
arg	−2.141	−0.498	−1.121	−0.663	−1.243	−1.039	−0.498
rame	−1.996	−1.013	−1.015	−0.554	−1.442	−1.091	−0.498
jpn	−1.888	−1.177	−1.295		−0.928	−1.029	−0.634
kor		−1.231			−0.498	−0.867	
chn	−1.888	−1.250	−0.880	−0.515	−1.095	−1.364	−0.554
reas		−1.413			−1.504	−1.514	−0.508
ceas		−1.162	−1.612	−1.399	−1.105	−1.713	−1.896
ind	−1.888	−1.361	−1.400	−1.301	−1.402	−1.248	−0.508
pak	−1.888	−2.048	−1.485	−1.019	−1.441	−1.506	−1.032
bgd			−1.500		−1.989	−1.497	−1.208
lka	−2.199	−1.163			−1.725	−2.913	−1.014
rsas	−2.800	−1.066	−0.880	−1.750	−1.120	−1.358	−1.105
idn	−1.888	−1.330			−1.775	−1.057	−2.135
mys	−1.915				−1.128	−1.091	−1.881

continued

Table 6 Growth of input of land per unit crop output (iolndc) continued

Region	whe	rce	mze	oce	pot	spo	ort
				iolndc			
	%	%	%	%	%	%	%
mmr	−1.888	−1.326	−1.400	−1.238	−1.471	−1.876	−0.896
phl	−2.421				−1.764	−1.175	−1.175
tha	−1.888	−1.194		−1.313	−1.696	−1.186	−0.637
vnm	−1.888	−1.243			−1.514	−1.231	−0.859
rsea	−1.888	−1.226			−1.944	−1.593	−2.127
weas	−1.888	−1.338		−0.879	−1.208	−1.466	−1.168
tur		−0.498	−0.880	−0.572	−1.006	−1.207	−1.162
eu15	−1.888	−0.498	−0.880	−0.498	−0.783	−1.282	−0.548
eeu		−1.459	−0.880	−1.056	−1.250	−1.906	−1.305
seu		−1.062	−0.880	−0.566	−1.724	−2.822	−1.158
reu	−1.888	−0.987	−0.942	−0.498	−1.342	−2.913	−0.751
aus		−0.824	−1.469	−1.400	−0.938	−1.257	−0.498
roce	−2.338		−2.043		−1.230	−1.273	−1.113
egy	−1.888	−0.498		−1.034	−0.860	−1.290	−0.498
nga	−2.032	−1.604			−2.155	−1.788	−1.550
rsa	−2.465	−1.526	−1.314	−1.211	−1.211	−0.560	−1.176
rnaf	−2.913	−2.072	−0.880	−1.094	−1.322	−1.653	−0.498
rmwf	−2.360	−2.006		−1.922	−2.223	−1.682	−1.420
rsef	−2.465	−1.474	−1.468	−1.316	−2.073	−1.714	−0.890

Note: Full names of commodities and regions used in the model are explained in tables 2 and 3.

Table 7 Growth of input of land per unit livestock product output (iolndl)

Region	bef	she	Region	bef	she
			iolndl		
	%	%		%	%
usa	−0.498	−0.498	phl	−1.125	−0.893
can	−0.636	−0.813	tha	−1.166	−0.965
mex	−1.183	−0.880	vnm	−1.248	−0.952
brz	−1.144	−0.968	rsea	−1.553	−1.509
arg	−1.153	−1.216	weas	−1.417	−0.867
rame	−1.175	−1.009	tur	−1.155	−0.911
jpn	−0.498		eu15	−0.942	−0.969
kor	−0.737	−0.952	eeu	−1.277	−0.967
chn	−1.438	−0.953	seu	−1.286	−1.057
reas	−1.534	−0.910	reu	−1.130	−0.867
ceas	−1.292	−0.711	aus	−1.186	−0.990
ind	−1.558	−0.829	roce	−1.186	−0.990
pak	−1.405	−0.922	egy	−1.219	−0.781
bgd	−2.099	−1.381	nga	−1.501	−1.051
lka	−1.538		rsa	−1.055	−0.883
rsas	−1.405	−0.935	rnaf	−1.394	−0.950
idn	−1.146	−1.149	rmwf	−1.512	−1.035
mys	−1.564	−1.135	rsef	−1.477	−1.089
mmr	−1.405	−1.166			

Note: Full names of commodities and regions used in the model are explained in tables 2 and 3.

Table 8 Growth of input of feed mix per unit output of livestock product (iofdmx)

	iofdmx					
Regions	bef	pok	she	pul	egg	mlk
	%	%	%	%	%	%
usa	−0.498	−0.498	−0.498	−0.498	−0.498	−0.498
can	−0.636	−0.568	−0.813	−0.810	−0.559	−0.763
mex	−1.183	−0.866	−0.880	−0.921	−1.018	−1.442
brz	−1.144	−0.541	−0.968	−0.831	−1.372	−2.805
arg	−1.153	−0.970	−1.216	−0.498	−0.749	−1.272
rame	−1.175	−1.023	−1.009	−0.966	−1.004	−2.341
jpn	−0.498	−0.913		−0.725	−0.498	−0.951
kor	−0.737	−0.931	−0.952	−1.410	−1.152	−1.049
chn	−1.438	−0.933	−0.953	−1.051	−1.094	−2.913
reas	−1.534	−1.221	−0.910	−1.165	−1.179	−2.913
ceas	−1.292	−1.049	−0.711	−1.120	−1.160	−2.404
ind	−1.558	−1.471	−0.829	−1.357	−0.963	−2.801
pak	−1.405		−0.922	−1.203	−1.602	−2.491
bgd	−2.099		−1.381	−1.533	−2.690	−2.913
lka	−1.538			−1.168	−1.551	−2.913
rsas	−1.405	−1.542	−0.935	−1.190	−1.145	−2.913
idn	−1.146	−1.163	−1.149	−1.479	−1.517	−2.913
mys	−1.564	−1.157	−1.135	−0.879	−1.281	−2.913
mmr	−1.405	−1.070	−1.166	−1.212	−1.593	−2.913
phl	−1.125	−1.054	−0.893	−1.229	−1.532	−1.846
tha	−1.166	−1.073	−0.965	−1.211	−1.271	−1.571
vnm	−1.248	−1.036	−0.952	−1.085	−1.751	−2.298
rsea	−1.553	−1.337	−1.509	−1.123	−1.651	−2.913
weas	−1.417	−1.013	−0.867	−1.196	−1.115	−2.913
tur	−1.155		−0.911	−0.869	−1.019	−2.913
eu15	−0.942	−0.588	−0.969	−0.866	−0.498	−1.598
eeu	−1.277	−0.670	−0.967	−1.017	−1.058	−1.723
seu	−1.286	−0.498	−1.057	−1.108	−1.264	−2.790
reu	−1.130	−0.758	−0.867	−1.085	−0.544	−1.195
aus	−1.186	−1.024	−0.990	−0.792	−1.102	−1.162
roce	−1.186	−1.248	−0.990	−1.016	−1.124	−1.400
egy	−1.219	−1.360	−0.781	−1.091	−0.909	−2.912
nga	−1.501	−1.288	−1.051	−1.299	−1.839	−2.913
rsa	−1.055	−0.787	−0.883	−1.048	−1.078	−1.368
rnaf	−1.394		−0.950	−1.179	−1.593	−2.913
rmwf	−1.512	−1.439	−1.035	−1.408	−2.015	−2.913
rsef	−1.477	−1.134	−1.089	−1.283	−2.069	−2.913

Note: Full names of commodities and regions used in the model are explained in tables 2 and 3.

Table 9 Growth in unit operating cost of livestock product supply (uopcl) (tcuopcli)

	tcuopcli					
	bef	pok	she	pul	egg	mlk
	%	%	%	%	%	%
Common world value	−1.169	−0.787	−0.945	−0.853	−0.971	−1.556

Note: Full names of commodities used in the model are explained in Table 2.

Table 10 Growth in unit operating cost of crop supply (uopcc) (tcuopcci)

	tcuopcci		
Commodities	Common world value %	Commodities	Common world value %
whe	−0.764	rap	−1.027
rce	−1.298	sun	−0.945
mze	−1.289	ovegml	−0.891
oce	−1.349	ovegol	−0.891
pot	−1.513	veg	−1.238
spo	−1.175	frt	−1.362
ort	−2.157	sugr	−0.699
soy	−0.701		

Note: Full names for commodities used in the model are explained in Table 2.

4 Model equations

This chapter details and explains equations used in the various components or 'blocks' of the model.

Crop production block

Crop supply arbitrage condition

```
qsceq(t,n,ic).. (plndc(t,n)*iolndc(t,n,ic))$ilc(ic)+uopcc(t,n,ic)≥ps(t,n,ic)
```

This is a price arbitrage condition used to determine the level of crop production. It is a mixed complementarity problem (MCP) condition because the condition is an inequality.

The generic interpretation of an MCP condition is as follows. If the inequality is strict, there is a gap between the right and left-hand sides, then the shadow value associated with the MCP condition, in this case qsc, should be zero. This is because the product of the shadow value and the gap between the right and left-hand sides of the MCP condition, the complementary slackness condition, must be zero. If the shadow value, which is qsc, is strictly positive, then the MCP condition holds with equality to meet the complementary slackness condition.

For the crop farmer, the left-hand side of qsceq represents the unit (and marginal) cost of crop production. Unit cost is greater than or equal to the price received, the marginal benefit (the right-hand side of qsceq). Following the generic interpretation of an MCP condition just given, production will be zero (to satisfy the complementary slackness condition) if the unit cost of production is above the price (the MCP condition is a strict inequality). Refer to a price quantity diagram of supply (cost) and demand (price). This is the case where production is not profitable. Alternatively if it is profitable to produce (qsc exceeds zero), this will occur at the point where the unit cost curve intersects the given price line (to satisfy the complementary slackness condition). This is where marginal net benefit is driven to zero and total net benefit from production is maximised.

In equation qsceq, the unit cost of crop production comprises the land rental cost per unit output (the first bracketed term) and unit operating cost (the second term). The latter is determined below.

In relation to land, typical crops compete for general crop land and land is used in fixed proportions to output. If the yield improves exogenously, then the input of land per unit crop output falls.

The expression `w(x)=(z)$y(x)` means w(x)=z if y is a subset of x, that is, w(y)=z. A land rental cost only applies for subset ilc(ic), crop commodities that compete for general crop land. With the general crop land term excluded, the above equation for qsc is also used for simplicity to represent the unit cost of supply for other vegetable meals and other vegetable oils. These are the end outputs from crop production activities that produce meals and oils that are not explicitly modelled here. By contrast and as shown below, oilseed crush complexes that are explicitly modelled are for soybeans, rapeseed and sunflower seed, throughputs for which crop land competition is explicitly specified.

Unit operating cost of crop supply

```
uopcceq(t,n,ic)..
uopcc(t,n,ic)/uopcc0(n,ic)=tcuopcci(t,n,ic)*(qsc(t,n,ic)/qsc0(n,ic))**(1/esc(n,ic))
```

This generic functional form is widely used in the model. It is a base year value scaled form of the log linear relationship z(t)=a0*tci(t)* y(t)**b. Relevant base year values are denoted by the suffix 0 and tci(t) is a technical change index with base year value of 1. In base year 0, z0=a0*1*y0**b so z(t)/z0=tci(t)*(y(t)/y0)**b.

In this equation, the unit operating cost curve slopes up with output and shifts down with exogenous input saving technical advance. The upward slope stops crop specialisation where crops compete for general crop land and reflects crop specific resource fixity. The own price elasticity of supply is accounted for through the flexibility term and cross-price effects come through land competition.

Crop land demand

lnddceq(t,n,ilc).. lnddc(t,n,ilc)=iolndc(t,n,ilc)*qsc(t,n,ilc)

In this equation, crop land demand is proportional to output.

Livestock production block

Livestock product supply arbitrage condition

qsleq(t,n,il)..(plndg(t,n,il)*iolndl(t,n,il))$ilg(il)+pdfdmx(t,n)*iofdmx(t,n,il)+uopcl(t,n,il)≥ps(t,n,il)

In general, the unit cost of livestock product supply comprises land, feed and unit operating cost terms. The addition of a unit production cost for livestock feed use distinguishes it from the specification for crop production.

Beef and sheep meat grazing enterprises are assumed to compete for grazing land, denoted by livestock product enterprises that use grazing land subset ilg. Grazing animals can use pasture land or crop land but will choose the least cost land type, and select the land with the lowest rental price, given a common land use coefficient (in turn a simplification reflecting data limitations). Reflecting the higher quality rent from land suitable for crops, crops can only be grown on crop land in the model. In the model a base level rent is earned on pasture land and crop land receives an endogenous price premium. The price premium shrinks (expands) with relatively profitable grazing (cropping) over crop (grazing) farming enterprises.

All livestock product activities use feed in fixed proportions and land if it is explicitly modelled. Dairy, pig and poultry operations are assumed to be highly intensive feed enterprises in each region of the model; for this reason competition by these enterprises for general pasture and crop lands is less relevant and not explicitly modelled. As with crops, improvements in production techniques for livestock products are incorporated through reductions in input–output coefficients and reductions in operating cost.

Unit operating cost of livestock product supply

uopcleq(t,n,il).. uopcl(t,n,il)/uopcl0(n,il)=tcuopcli(t,n,il)*(qsl(t,n,il)/qsl0(n,il))**(1/esl(n,il))

This equation is analogous to crop supply. Operating cost covers costs of livestock product supply, other than land and feed, as applicable.

Grazing enterprise land rental balance

plndgeq(t,n,ilg).. iolndl(t,n,ilg)*qsl(t,n,ilg)≤lnddgc(t,n,ilg)+lnddgp(t,n,ilg)

In this equation, the demand for land by the grazing enterprise (the left-hand side) cannot exceed its rental supplies of crop and pasture land (the right-hand side). If there is always an excess supply of grazing land, then its rental price is zero. Otherwise the rental price is that which equates aggregate local demand and supply.

Grazing enterprise crop land demand arbitrage condition

lnddgceq(t,n,ilg).. plndc(t,n)≥plndg(t,n,ilg)

In this equation if crop land is not used for grazing, lnddgc=0, it is because its marginal rental cost (the left-hand side) exceeds its marginal user benefit for grazing (the right-hand side). If it is used, lnddgc>0, then this is done to the optimal point where the marginal net benefit is zero.

Grazing enterprise pasture land demand arbitrage condition

lnddgpeq(t,n,ilg).. plndp(t,n)≥plndg(t,n,ilg)

This equation is analogous to that for crop land demand.

Fish production block

Fish supply arbitrage condition

qsfeq(t,n,ifs).. pren(t,n,ifs)$ifsc(ifs)+(pd(t,n,'fimo')*iofdaq(t,n))$ifsa(ifs)+

uopcf(t,n,ifs)≥ps(t,n,'fishvd')$ifishs(ifs)+ps(t,n,'fislvd')$ifisls(ifs)

This equation deals with capture fisheries and aquaculture, respectively.

A captive fishery (subset ifsc of ifs) is constrained to produce within or on the exogenously set quota, depending on what is most profitable. The total unit cost of a captive fishery must cover the rental price of quota, pren, plus the unit operating cost of fishing, uopcf.

In the model, low and high quality fish are distinguished and the latter receives a potential price premium. Each of the capture fisheries produces one given type of fish. In addition, there is an aquaculture enterprise in each region that produces high quality fish product that competes directly with the high quality product from the relevant capture fishery. Aquaculture uses fish meal and oil concentrate (fimo) as feed in fixed proportions to output. This is in addition to other inputs represented again using a unit operating cost curve. Fish meal and oil concentrate is produced from fish using a reduction process, as described below. Low or high quality fish may be used for reduction but the least cost choice will typically favour low quality.

Unit operating cost of fish supply

uopcfeq(t,n,ifs).. uopcf(t,n,ifs)/uopcf0(n,ifs)=tcuopcfi(t,n,ifs)*

(qsf(t,n,ifs)/qsf0(n,ifs))**(1/esf(n,ifs))

The standard form for unit operating cost is used here. This covers costs other than feed and the rental cost of quota, as applicable.

Capture fishery quota constraint

preneq(t,n,ifsc).. qsf(t,n,ifsc)≤qsf0(n,ifsc)*gafi(t,n,ifsc)

In this equation, annual production (left-hand side) must lie within or on quota (right-hand side). The quota is base year production adjusted by an index that reflects an assumed path for sustainable production from the region’s capture fishery. The rental price of quota is nil if the quota is not filled. Otherwise, the rental price is found where the level of production equates demand with the quota limit. The rental price is then the price received net of unit operating cost.

Aquaculture demand for fish meal and oil concentrate

qdfimoaqeq(t,n).. qdfimoaq(t,n)=iofdaq(t,n)*qsf(t,n,'fisaqus')

The demand by aquaculture for fish meal and oil concentrate is in direct proportion to output.

Fish reduction block

Fish throughput for reduction arbitrage condition

qdfrdeq(t,n,ifisd).. pd(t,n,ifisd)+uopcfrd(t,n)≥opipfrd(t,n,ifisd)*ps(t,n,'fimo')

In this equation fish processing for reduction to fish meal and oil concentrate occurs if the marginal benefit received (the right-hand side) exactly covers the unit cost of production (the left-hand side). The benefit is the price received for fish meal and oil concentrate times the fixed output of fish meal and oil concentrate per unit input of fish. The unit cost of fish for reduction is the consumer's price plus a unit processing cost for fish throughput. Fish for reduction may be of high or low quality, but for reduction are distinguished only by price as modelled here, and the lowest cost economic source is the one that will be used. The endogenous price premium for high quality fish reflects imperfect substitution between low and high quality fish in human fish consumption, see the demand section below.

Unit operating cost of fish throughput for reduction

uopcfrdeq(t,n).. uopcfrd(t,n)/uopcfrd0(n)=tcuopcfrdi(t,n)*

(qdfrdtot(t,n)/qdfrdtot0(n))**(1/esfrd(n))

The standard form for unit operating cost is used here for fish reduction, with one exception. Unit cost increases with fish throughput rather than fish output. Unit operating cost comprises other than the direct cost of fish for reduction. For simplicity, and reflecting some data limitations, fish for reduction in the model represents fish product of commercial value; that is, fish directly from fish capture or aquaculture farming rather than from by-product waste. In turn it is the fish meal and oil concentrate from reduction that is used as fish feed in aquaculture, as modelled here.

Total fish throughput for reduction

qdfdrtoteq(t,n).. qdfrdtot(t,n)=sum(ifisd,qdfrd(t,n,ifisd))

Total throughput for reduction is the sum of throughputs from low and high quality sources.

Total fishmeal and oil concentrate production

qsfimoeq(t,n).. qsfimo(t,n)=sum(ifisd,opipfrd(t,n,ifisd)*qdfrd(t,n,ifisd))

Total fish meal and oil concentrate produced is the sum of fish meal and oil concentrate produced from each throughput source, according to fixed output per unit input relationships.

Oilseed crush complex block

Crush throughput arbitrage condition

qdcrueq(t,n,icruip).. pd(t,n,icruip)+uopccru(t,n,icruip)=pdcrustar(t,n,icruip)

There is zero pure profit in crushing the relevant oilseed to produce meal and oil. The unit cost of production is the price of the throughput plus a unit operating cost for crushing. The price or unit revenue from the crush is defined next.

Price of crush complex composite output

pdcrueq(t,n,icruip).. pdcrustar(t,n,icruip)*qdcru(t,n,icruip)=

sum(icruopml$dvcrush(icruip,icruopml),ps(t,n,icruopml)*qscrml(t,n,icruopml))+

sum(icruopol$dvcrush(icruip,icruopol),ps(t,n,icruopol)*qscrml(t,n,icruopol))

In this equation, unit revenue from the crush is the value of output from meal and oil divided by the volume of throughput. The dummy variable dvcrush pairs the oilseed input type with the relevant oilseed output type.

Unit operating cost of crush throughput

uopccrueq(t,n,icruip).. (uopccru(t,n,icruip)/uopccru0(n,icruip))=tcuopccrui(t,n,icruip)*

(qdcru(t,n,icruip)/qdcru0(n,icruip))**(1/escru(icruip,n))

The functional form for the unit operating cost of crush throughput is the same as that used for fish throughput for reduction. The unit operating cost relates to processing costs, excluding the direct cost of purchasing the oilseed throughput.

Crush output of meal

qscrmleq(t,n,icruopml).. (qscrml(t,n,icruopml)/qscrml0(n,icruopml))/

sum(icruip$dvcrush(icruip,icruopml),qdcru(t,n,icruip)/qdcru0(n,icruip))=

(ps(t,n,icruopml)/ps0(n,icruopml))/

sum(icruip$dvcrush(icruip,icruopml),pdcrustar(t,n,icruip)/pdcrustar0(n,icruip))

Crush outputs of meal and oil are produced according to a Cobb–Douglas transformation function, as assumed here. Accordingly from this equation, the growth rate in the output of meal relative to throughput (the left-hand side) equals the growth rate in the price of meal relative to the unit revenue from the crush, which is the price of the composite crush output. Hence, the meal ratio to crush throughput rises with its output price relative to the price of the composite crush output. Combined with the next equation, this means the ratio of meal to oil increases as the price of meal to oil increases.

Crush output of oil

qscroleq(t,n,icruopol).. (qscrol(t,n,icruopol)/qscrol0(n,icruopol))/

sum(icruip$dvcrush(icruip,icruopol),qdcru(t,n,icruip)/qdcru0(n,icruip))=

(ps(t,n,icruopol)/ps0(n,icruopol))/

sum(icruip$dvcrush(icruip,icruopol),pdcrustar(t,n,icruip)/pdcrustar0(n,icruip))

This is symmetric to meal.

Generic feed mix complex block

Price of generic feed mix

pdfdmxeq(t,n).. pdfdmx(t,n)=sum(ifd,pd(t,n,ifd)*qdfdfmx(t,n,ifd))/qfdmxact(t,n)

There is zero pure profit in creating the generic mix used for livestock feed in a region. Specifically in this equation the price of the feed mix equals the value of the feed inputs divided by the quantity of feed mix created.

Demand for ingredient to generic feed mix

qdfdfmxeq(t,n,ifd).. (qdfdfmx(t,n,ifd)/qdfdfmx0(n,ifd))/(qfdmxact(t,n)/qfdmxact0(n)) =

((pdfdmx(t,n)/pdfdmx0(n))/(pd(t,n,ifd)/pd0(n,ifd)))**sigmamx(n)

A constant elasticity of substitution, called sigmamx, is imposed across the ingredients to the generic feed mix. Accordingly from this equation the growth rate in the demand for the feed mix ingredient, relative to the total feed mix produced (the left-hand side), equals sigmamx times the growth rate in the price of the generic mix, relative to the feed ingredient. Hence, from this equation a one percent increase in the price of an ingredient reduces the ingredient in the mix by sigmamx, other things equal.

Volume of generic feed mix consumed by animal type

qfdanleq(t,n,il).. qdfdanl(t,n,il)=iofdmx (t,n,il)*qsl(t,n,il)

Given the Leontief livestock production technology discussed earlier, the volume of feed mix consumed by each livestock type is proportionate to the volume of livestock product output.

Total generic feed mix produced

qfdmxacteq(t,n).. qfdmxact(t,n)=sum(il,qdfdanl(t,n,il))

In the model, total generic feed mix produced in a region is what is consumed in the region. This is the sum of uses across all livestock types.

Land market balances and total production by commodity

Crop land balance

plndceq(t,n).. lndsc(t,n)≥sum(ilc,lnddc(t,n,ilc))+sum(ilg,lnddgc(t,n,ilg))

From the algebra in this equation, the supply of crop land is greater than or equal to the demands for that land by crop and grazing enterprises in a region. Hence, both crop and grazing enterprises can compete for crop land and demand is the sum across all potential crop and pasture uses. From economic principles for market balance, price rations supply to users on the basis of derived demand to meet agricultural production requirements. Marginal value benefits are equalised across all actual uses. Land supply determination is discussed below.

Pasture land balance

plndpeq(t,n).. lndsp(t,n)≥sum(ilg,lnddgp(t,n,ilg))

The pasture land balance in a region is similar to crop land except that only grazing enterprises compete for pasture land, which is why there are only livestock demand terms in the right-hand side of the equation.

Crop land supply arbitrage condition

lndsceq(t,n).. plndc0(n)*(lndsc(t,n)/lndsc0(n))**(1/eslndc(n))+plndctax(t,n)≥plndc(t,n)

Crop land supply is upward sloping in the land rental price up to a feasible fixed upper limit. The supply curve is vertical beyond this point. If crop land is not used, it is because its cost exceeds its marginal value benefit.

Pasture land supply arbitrage condition

lndspeq(t,n).. plndp0(n)*(lndsp(t,n)/lndsp0(n))**(1/eslndp(n))+plndptax(t,n)≥plndp(t,n)

The pasture land supply arbitrage condition is similar to crop land.

Crop land supply absolute upper limit

plndctaxeq(t,n).. lndscmax(n)≥lndsc(t,n)

If crop land is less than its assumed feasible fixed upper limit, the shadow tax on available crop land is zero, otherwise the quota is binding and the shadow tax is positive.

Pasture land supply absolute upper limit

plndptaxeq(t,n).. lndspmax(n)≥lndsp(t,n)

The pasture land supply absolute upper limit has the same interpretation as crop land.

Total local production by commodity definition

qstoteq(t,n,i).. qstot(t,n,i)=(qsc(t,n,i))$ic(i)+qsl(t,n,i)$il(i)+

sum(ifs$dvmkfis(ifs,i),qsf(t,n,i)))$ifisd(i)+

qsfimo(t,n)$ifimo(i)+qscrml(t,n,i)$icruopml(i)+qscrol(t,n,i)$icruopol(i)

Total production of each potentially international traded commodity is defined in this equation. The interpretation of $im(i) means only do this for subset im in i. In this equation, each primary cropping (qsc subset ic) and livestock production activity (qsl subset il) produces a single product. Note that this is the sum of all primary equivalent sources of demand. For the fishing activities, the three supplies (qsf subset ifs), from the two capture fisheries and from aquaculture farming, need to be mapped into market demands (qstot subset ifisd) for high and low quality fish according to the dummy mapping fish supplies to fish demand types (dvmkfis).

In this equation, production from the secondary processing activities modelled relate to the production and use of fish meal and oil concentrate (qsfimo subset ifimo) and to the oilseed complex meal (qscrml subset icruopml) and oil (qscrol subset icruopol) outputs from crushing of soybeans, rapeseed and sunflower seeds, respectively.

Demand for food, feed and other uses, and total consumption by commodity

Food demand by composite commodity group

qdfoaggeq(t,n,iagg).. log(qdfoagg(t,n,iagg)/qdfoagg0(n,iagg))=

edfoincagg(iagg,n)*log(ginci(t,n))+

sum(jagg,edfopagg(iagg,jagg,n)*log(pdfoagg(t,n,jagg)/pdfoagg0(n,jagg)))

A two-level nested specification is used to specify food demand. At the top level, consumers choose the levels of food commodity groups in set iagg (see definition in Table 1) according to a log linear demand function. This function shifts out with exogenous real income growth according to the income elasticity of demand. The curve slopes down with own price and shifts out with increases in the price of substitute products. In particular, the growth rate in the demand for a composite food group item (the left-hand side) equals the relevant income elasticity weighted growth rate in income plus the own and cross-price weighted elasticity sum of the growth rates in the real price of each composite food commodity type (the right-hand side).

The second level involves choosing between items in a food commodity group according to a constant elasticity of substitution function, see below.

Price of composite food commodity

pdfoaggeq(t,n,iagg).. pdfoagg(t,n,iagg)=

sum(ifo$dvfdagg(ifo,iagg),pd(t,n,ifo)*qdfo(t,n,ifo))/qdfoagg(t,n,iagg)

In this equation, the value of each composite food commodity is the sum of the values of its parts.

Demand for food commodity

qdfoeq(t,n,ifo).. (qdfo(t,n,ifo)/qdfo0(n,ifo))/

sum(iagg$dvfdagg(ifo,iagg),qdfoagg(t,n,iagg)/qdfoagg0(n,iagg))=

gtastesubi(t,n,ifo)*

(sum(iagg$dvfdagg(ifo,iagg),(pdfoagg(t,n,iagg)/pdfoagg0(n,iagg)))/

(pd(t,n,ifo)/pd0(n,ifo)))**sum(iagg$dvfdagg(ifo,iagg),sigmafo(n,iagg))

Reflecting the constant elasticity of substitution functional form, from this equation the growth rate in the demand for a food commodity, relative to that for the corresponding composite food aggregate (the left-hand side), equals the growth rate in the taste index for the commodity plus sigmafo times the growth rate in the price of the composite commodity relative to the price of the specific commodity. From this equation, demand for a commodity in a food group will increase by sigmafo per cent in response to a 1 per cent increase in the price of a substitute item in the food group, where sigmafo is the ces elasticity of substitution between foods in the food type.

Total feed demand definition

qdfdeq(t,n,ifdt).. qdfd(t,n,ifdt)=qdfdfmx(t,n,ifdt)$ifdd(ifdt)+qdfimoaq(t,n)$ifimod(ifdt)

In the model, commodity demand for product as feed is either for generation of the generic local livestock production mix (qdfdfmx for subset ifdd), if it is a crop or oilseed meal, or it refers to fish meal and oil concentrate (qdfimoaq for subset ifimod) that is used as feed by aquaculture.

Other miscellaneous demand for agrifood products

qdmseq(t,n,ims).. qdms(t,n,ims)=shms(t,n,ims)*qdtot(t,n,ims)

If agrifood product has non-food uses, such as for biofuel production, then this endogenous demand is incorporated in the model as an exogenous share of total endogenous demand.

Total consumption definition

qdtoteq(t,n,i).. qdtot(t,n,i)=qdfo(t,n,i)$ifo(i)+qdfd(t,n,i)$ifdt(i)+qdfrd(t,n,i)$ifisrd(i)+ qdcru(t,n,i)$icruip(i)+qdms(t,n,i)$ims(i)

Total use of each commodity (over set i) in the model is defined here. Some products are used for food (subset ifo), to make the generic feed mix for livestock or to feed aquaculture (subset ifdt). Other products are used to make fish meal and oil concentrate (subset ifisrd), while some products are crushed to make meal and oil (subset icruip), and other agrifood products have miscellaneous uses (subset ims).

Prices and trade block

Producer price definition

pseq(t,n,i).. ps(t,n,i)=pg(t,n,i)*(1+pse(t,n,i))

In this equation the producer price is the domestic market price inflated by the exogenous *ad valorem* producer support estimate.

Export parity price definition

pexptfobeq(t,n,i).. pexptfob(t,n,i)=pw(t,i)−tc(t,n,i)

The export parity price is the world price less the exogenous unit transport cost from the domestic to the world market.

Consumer price definition

pdeq(t,n,i).. pd(t,n,i)=pg(t,n,i)*(1−cse(t,n,i))

The consumer price is the domestic market price deflated by the exogenous *ad valorem* consumer support estimate.

Import parity price definition

pimptcifeq(t,n,i).. pimptcif(t,n,i)=pw(t,i)+tc(t,n,i)

The import parity price is the world price plus the exogenous unit transport cost from the world to the domestic market.

Domestic market balance

pgeq(t,n,i).. qstot(t,n,i)+impt(t,n,i)≥qdtot(t,n,i)+expt(t,n,i)

For each potentially internationally traded good in the model, supply from domestic and foreign sources is greater than or equal to demand from domestic and foreign sources. In the model two-way trade is ruled out as it will be profitable to either export, not trade or import, respectively, see below.

Export arbitrage condition

expteq(t,n,i).. pg(t,n,i)≥pexptfob(t,n,i)

If the cost to export exceeds the export parity price, then exports will not occur. Otherwise, exporting takes place up until the point that the unit cost equals the price benefit.

Import arbitrage condition

impteq(t,n,i).. pimptcif(t,n,i)≥pg(t,n,i)

If the import parity price exceeds the local product cost, imports will be nil. Otherwise importing takes placed up until the point that the marginal net benefit is zero. From the above conditions, the local price differs at most from the world price by twice the unit transport cost to and from the world market, as occurs if trade is unprofitable (autarky).

Global market balance

pweq(t,i).. sum(n,expt(t,n,i))≥sum(n,impt(t,n,i))

In this equation the world market clears when the sum of exports from all regions balances the sum of imports to all regions. This occurs when the world price adjusts so that global demand balances global supply. In principle a product's world price could be nil if there is excess supply of the product, such that the aggregate inverse demand function is everywhere below the aggregate inverse supply function; that is, where the choke price is lower than the unit cost of production in a world market diagram.

Given the MCP structure, overall price and trade determination may be explained from the price and trade block as follows. The domestic price of a traded commodity is bounded from below by the export parity price and from above by the import parity price. The world price is determined from the global market balance between export supplies and import demands. Equation pweq holds as an equality as world price is strictly positive (to satisfy the complementary slackness condition).

Three situations are possible for regional trade:

- Case A: If the domestic price is lower than the export parity price under autarky, then with trade it is profitable to export until the price equals the export parity price. With exports strictly positive, equation expteq holds with equality, and domestic price is determined from the export parity price, which is the world price less the unit transport cost. Since the domestic price is strictly positive, the domestic market balance pgeq holds with equality and is used to determine the volume of exports.

- Case B: If the domestic price is higher than the import parity price under autarky, then with trade it is profitable to import until the price equals the import parity price. In this case, the domestic market balance is used to determine the volume of imports.

- Case C: If the domestic price is higher than the export parity price and lower than the import parity price under autarky, then trade is not profitable and is nil. The domestic market balance equation holds with equality and local demand balances local supply to determine the local price.

5 Data sources

The model is calibrated to base year data and simulated over time using shocks to select exogenous variables. The main source of base year data for quantity commodity balances and representative world prices is the Food and Agriculture Organization of the United Nations (FAO 2011). GTAP database version 7.1 data was a key source for calibrating cost shares for feed and land use (GTAP 2010).

In the projections reported in Linehan et al. (2012), exogenous variables are either constant, set at their base year value, or vary over time.

Constant exogenous variables

Unit transport cost wedges are ABARES' estimates. Base year producer support and consumer subsidy estimates are based mainly on OECD sources (2011). These are *ad valorem* wedges that separate producer and consumer prices on the domestic market. Physical limits imposed on agricultural land expansion are ABARES' estimates.

Time varying exogenous variables

Regional real income growth rates are ABARES' assumptions.

In general, technical change terms (productivity assumptions) are used to reduce land, feed and other input use per unit output of crop and livestock products. Costs of other inputs (other than land and feed) per unit output fall proportionately around the world in line with the equivalent reductions in global land and feed use, as relevant.

Changes in the input–output coefficients by region and over time are ABARES' assumptions formed about yields.

Changes in yields by 2050 relative to 2007, reflect historical trends and some degree of technical catch-up by developing countries toward technology leaders, primarily the United States. In all cases each region's yield for any given commodity could grow no more than 3 per cent a year over the long term. Otherwise, and typically, yield could improve to the greater of its historic maximum and the value assigned from technology catch-up. Technology catch-up was measured by an increase in the ratio of a region's yield for a commodity relative to that of the technology leader. For developing countries, technology catch-up was not assumed to be complete over the projection period. For developed countries, the yield ratio, relative to the technology leader, was maintained so that yield growth reflects growth by the technology leader.

It is noted that changes in the exogenous assumptions can affect the model-based projections, particularly over a long period, because small growth rates cumulate to large overall percentage changes. There is substantial scope for research that tests and refines the exogenous assumptions to account for uncertainty regarding these assumptions. In particular, scenario analysis could be used to analyse the sensitivity of the projections to the exogenous assumptions.

Elasticities

Model elasticities are ABARES' assumptions, drawing on the literature. Another avenue for research is to consider refining the food demand side specification to a per capita one where elasticities differ by income groups and to reflect this over time as regions undergo economic development.

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