Improving Phosphorus and Nitrogen Tracking in a Computable General Equilibrium Model: An Assessment of the Implications of Additive (Quantity Preserving) Production Functions.

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Abstract:

This paper aims to evaluate whether different specifications of production functions in a Computable General Equilibrium (CGE) model are significant when conducting environmental impact assessments. For this reason, the CGE MAGNET has been expanded with different new modules to better represent Nitrogen and Phosphorus producing sectors (i.e. representation of both chemical and organic fertilisers and general improvement in structuring the livestock production system). Furthermore, it tested the implications of the implementation of a quantity preserving function instead of a regular CES function for products that have a relevant associated physical quantity of nutrients. In this case, the focus was tailored to organic and chemical fertilisers since their Nitrogen and Phosphorus footprint are critical elements of the planetary system as well as two key planetary boundaries. The paper shows that the two different types of production structures lead to a consistent difference in the results. As such, the choice between the two options could significantly influence the political choices assessed through modelling. Therefore, the paper concludes that implementing a quantity preserving function is recommended when dealing with physical quantities and variables that need particular attention with regard to the physical values they rely on, as it is crucial for both the environment and their repercussions in the political arena.

1. Introduction

Environmental questions are at the core of our century's challenges. In particular, how to ensure basic needs and at the same time that the world does not exceed the planetary boundaries that would create permanent change to the planet's system is an issue that has been addressed by a large part of academia (Foley, 2010; Richardson et al., 2023; Rockström et al., 2009; Steffen et al., 2015). The Nitrogen and Phosphorus use boundary is a particularly important one (de Vries et al., 2013; Peñuelas & Sardans, 2022), as many countries have far exceeded it, and it has sensitive ties with the issues of food production and food security. Indeed, Nitrogen and Phosphorus applications are key inputs for agricultural and livestock production, whose pressure is expected to increase, mirroring the growth trends of population and food demand. For this reason, there is a clear necessity to have precise instruments for assessing the nutrient application repercussions when simulating different scenarios or policies. As such, this paper assesses the implications of the expansion of the Computable General Equilibrium (CGE) Model MAGNET with regard to a) the inclusion of both organic and non-organic sources of nutrients b) implementing a quantity preserving (QP) function for nutrient sources. To do so, section 2 introduces the methodology, the relative improvements and the design of the experiment, section 3 describes and analyses the results, section 4 concludes.

2. Methodology and Experiment Design

The paper provides an analysis of nutrient application and possible policy options using a Computable General Equilibrium model, MAGNET (Woltjer et al., 2014), explicitly extended to assess materials flows of nutrients and phosphorus from both chemical and organic sources. As such, it introduces manure as a livestock byproduct and factor of production, which allows for a better representation of both the livestock and crop sectors and their environmental footprint. The regional and sectoral aggregation used in this paper are reported in Figure F1 and Table T1 in the Supplementary Information.

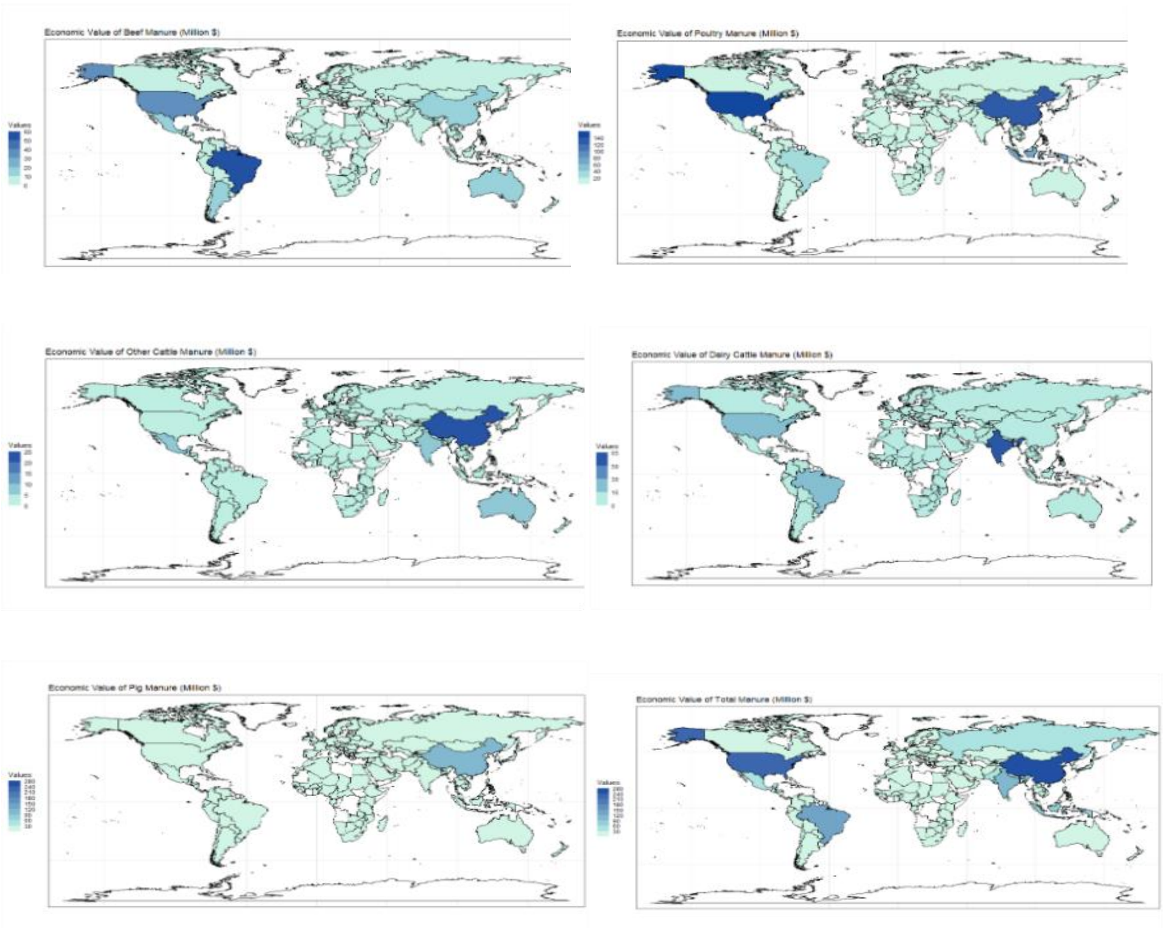
2.1 Introduction of organic nutrient sources in the model.

Manure is an important commodity produced by the livestock sectors, and a critical factor influencing the economic and environmental performance of the agricultural sectors, due to their relevant role in the provision of in Phosphorus and Nitrogen. Moreover, manure is a necessary by-product of the livestock sectors, therefore it could potentially be considered a zero-price commodity, though it has an implicit value due to its nutrient components. In MAGNET there are five livestock-based sectors which are considered suitable for manure production: beef cattle, dairy cattle, pigs, poultry and other cattle. The data on the nutrient intensities of manure are retrieved from the OECD Agri-environmental Indicators Database[1]. The database reports the Nitrogen and Phosphorus intensity of manure (in tonnes) of five different types of Livestock: Cattle, pigs, poultry, sheep and goats, and other livestock. The OECD data are available from 1990 to 2021 for 52 countries, which include all EU28 countries and some non-OECD economies (e.g. Brazil, India, China, Vietnam). The total nutrient values are obtained by summing up the available data in tonnes of Phosphorus and

[1] https://data-explorer.oecd.org/vis?lc=en&df[ds]=dsDisseminateFinalDMZ&df[id]=DSD_AGRI_ENV%40DF_NB&df[ag]=OECD.TAD.ARP&df[vs]=1.0&dq=.A.B0_H....&pd=2012%2C&to[TIME_PERIOD]=false&vw=tb

Nitrogen. Neither the country nor the sectoral details of the OECD data match directly with the MAGNET requirement. Therefore, the OECD values have been adjusted to match MAGNET's sectors on the basis of the proportion of the value added in its livestock sectors. The OECD values have been adjusted to match the MAGNET ones following the mapping reported in Table T2 in the Supplementary Information. Nevertheless, MAGNET is based on an economic database, which reports the economic value of the products and flows in million dollars. For this reason, data on prices for sector-specific manure have been retrieved from (Brown, 2021). The mapping between the two sets of livestock in MAGNET and the Brown data is reported in Table T2 in the Supplementary Information. Due to the absence of regionally detailed data on the estimates of manure prices, the average per livestock prices retrieved from Brown (2021) where applied to all the OECD countries. The final results is a database that reports the economic value for different types of manure at the global level (Figure 1).

Figure 1. Manure value by Livestock Category per Country.



Manure is then introduced as a production factor in three different sub-groups: crops, livestock and biogas. The structure of the relative production functions are reported in Figure F2 in the Supplementary Information. In general, manure is introduced as a competitor of chemical inputs such as fertilisers. In the case of livestock, manure is introduced as a production inputs since it is used to grow the feed for the livestock. Finally, for what concerns the biogas production structure, manure is introduced as an alternative feedstock. Other feedstocks are monocrops, landfill gas and residues and waste from crop production.

2.2. Quantity Preserving Production Function

In general, manure enters the productions structures to be a competitor of chemical inputs of production such as the fertilisers. In the case of livestock manure is introduced as production inputs because it is used to grow the feed for the livestock. For what concerns the biogas production structure, instead, manure is introduced as an alternative feedstock. Other feedstocks are monocrops, landfill gas and residues and waste from crop production. In order to better track Phosphorus and Nitrogen application in MAGNET, a quantity-preserving function is being introduced in place of the standard Constant Elasticity of Substitution (CES) production function for the nutrient-producing commodities. In doing so, the model becomes capable of preserving additivity of nutrient-based commodities, i.e. the sum of the volumes of the single components adds up to the total volume. The integration of additivity preserving functions in the model has been operated on the basis of the CES function assumed for production/supply in MAGNET on the basis of the methodology proposed by van der Mensbrugghe and Peters (Dixon & Rimmer, 2006; Giesecke et al., 2013; Van Der Mensbrugghe & Peters, 2016). This would allow to ensure that the sum of volumes of the single components adds up to the total volume. The quantity preserving feature is extremely useful in several cases, for example, to ensure that total land supply across land uses adds up to total available land (Fujimori et al., 2014), or that the allocation of national production is correctly accounted for between domestic and trade uses. The initial structure of production in MAGNET is based on different nested CES production functions. The standard linearized equation applied to each nest of the function is described in Eq. 1.

$$\textbf{Eq. 1} \quad pfa(i,j,r) = \sum NI(k,j,r) * [pfa(k,j,r) - afa(k,j,r)]$$

Where pfa is the price of the commodity i produced by sector j in region r by the specific nest, NI is the nest inputs by input commodity k, sector j, and region r (e.g. primary inputs or other intermediates that would act as inputs in the specific nest) and afa is the technological productivity change by commodity i, sector j, region r. This production function has therefore been updated for nutrient-producing commodities (chemical and biological fertilizers) with a function as the one presented in Eq. 2.

$$\textbf{Eq. 2} \quad pfa(i,j,r) = \sum NI(k,j,r) * [pfa(k,j,r) * qfa(k,j,r)] - qfa(k,j,r)$$

Where qfa is the intermediate quantities of commodities asked for production in the nest. A Description of the code changes introduced to implement the new function can be found in Section 2 of the Supplementary Information.

2.3 Footprint Calculation.

The MAGNET model is an economic CGE, and, as such, only tracks monetary values, as based on MRIO tables. To assess physical quantities, additional material balances are computed for specific variables in order to track “dollar-based quantities”. These values are cleaned for all non-material components, such as tariffs or transport costs (Gatto et al., 2023; Kuiper et al., 2025). The tracing of the physical quantities is then derived through the Leontief inverse approach, which identifies the intermediate demand over total output and then tracks back to domestic and foreign sources the final consumption of each region, a methodology used, for example, in (Lenzen et al., 2021).

2.4. Experiment design.

This implementation has been tested first by running a baseline scenario both with the quantity preserving option and without.

Baseline scenarios are generally used in CGE impact assessments to create the status quo against which the subject of the study is evaluated against (policy or shock). In this case, the baseline consists of the following assumptions:

- GDP, population, factor productivity and globalisation from SSP2 (Riahi et al., 2017)

- labour supply from the Wittgenstein Centre[2].
- Efficiency of feed use over time, based on IMAGE data (Stehfest et al., 2014)
- Nuclear energy, biofuels and Grassland are assumed to be fixed to 2017.

Then the scenarios assessment were performed in order to test the results and model behaviour against an hypothetical policy shock. As such, two scenarios, one with the quantity preserving function and one without, were tested against the implementation of a tax on chemical fertilisers up to 2050. The tax is implemented on all chemical fertilisers (Nitrogen, Phosphorus and Potassium) to avoid creating a hidden subsidy for potassium and was set as a 20% increase for each time step, starting from the base year 2017.

3. Results

The implementation of a quantity preserving function leads to significant changes in the results of the model, as the baseline projections up to 2050 already show some differences in regional footprints. Indeed, while the total Nitrogen and Phosphorus footprint for the EU27 region does not seem to be significantly affected, a difference in the aggregated Rest of the World footprint is noticeable. This already shows the importance of implementing a quantity preserving function on environmental footprint-relevant variables, as it could affect the overall level of projected impact (Figure 2).

Analysing the composition of the results, it seems that most of the adjustment between the preserving and not preserving impact is driven by the domestically consumed production of the countries. On the other hand, the contribution to nutrient footprint of traded products seems to be consistently overestimated.

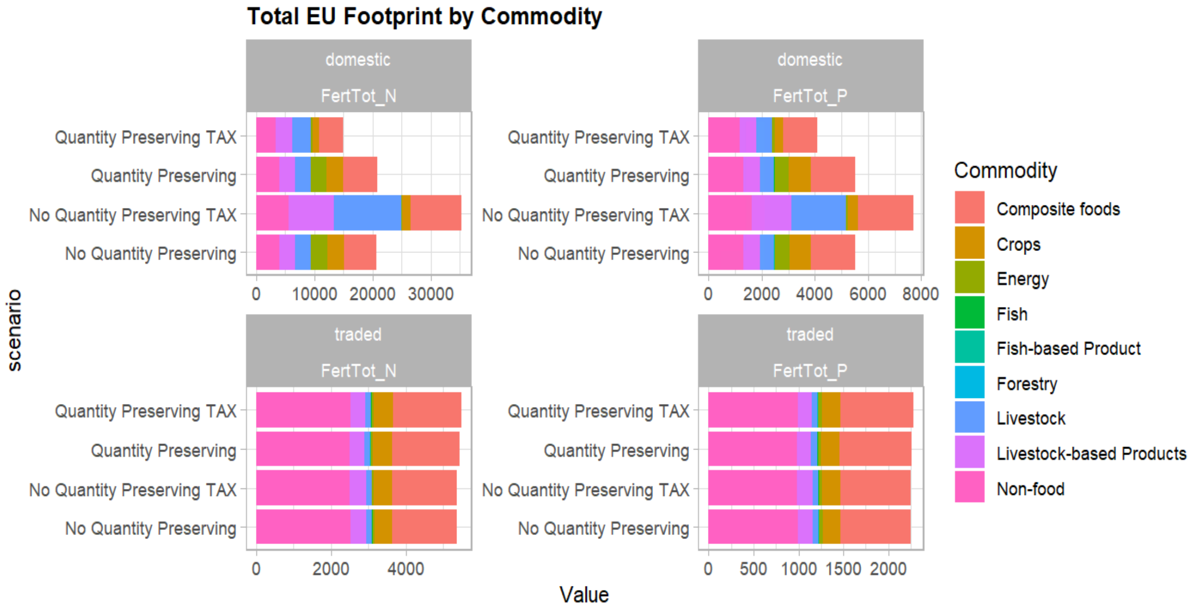
[2] https://dataexplorer.wittgensteincentre.org/wcde-v2/

Figure 2. Domestic and International Nutrient Footprint with and without QP

Nevertheless, when a tax on intermediate and imported uses of chemical fertilisers is imposed in a region, in this case the EU, implementing (or not) a quantity preserving function leads to significant differences in the overall impact for the affected region (Figure 3). Indeed, while the rest of the world seems relatively unaffected due to the balancing out of regional trade effects coming from the EU, it is clear that implementing different functions could lead to significant changes in the footprint of the affected region, leading to crucial implications for the evaluation of the policies efficiency. Figure 4 shows how most of the difference in the nutrient footprint comes from the domestic consumption of livestock products and composite foods.

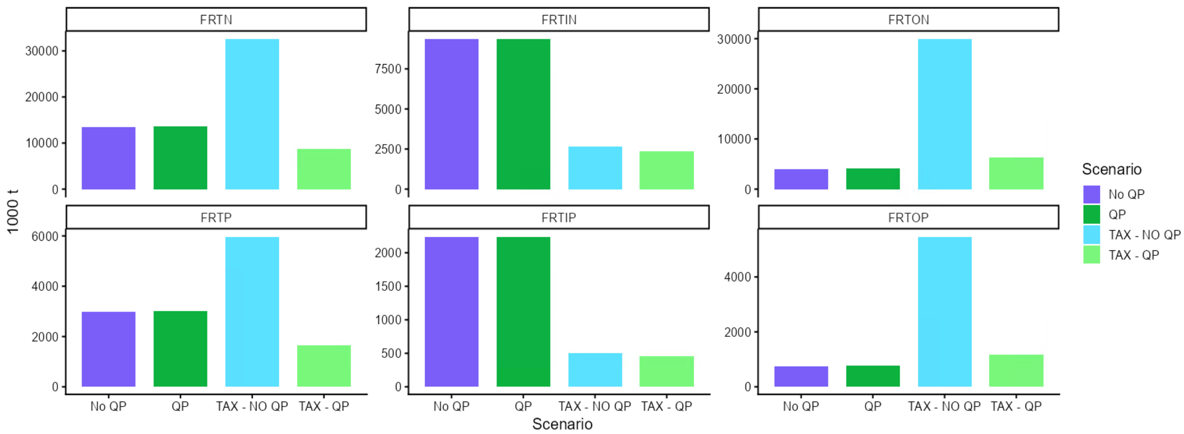
Figure 3. Domestic and International Nutrient Footprint with and without QP in different scenarios

Figure 4. Domestic and Imported Eu footprint by scenario.



To understand the reason behind the difference in the footprint of the two tax scenarios, it is useful to look at the impact on all types of fertilisers, that is both chemical and organic (i.e. manure). As shown by Figure 5, most of the difference in the footprint is due to the quantity of organic fertilisers used in domestic production, which is overestimated in the case in which the quantity preserving function is not included (Figure 4). This finding provides a particularly relevant insight on the importance of using quantity preserving functions for environmental policy assessment, as its absence would lead to an underestimation of the efficiency of the policy.

Figure 5. Total, inorganic and organic Nitrogen and Phosphorus use in EU by scenario.



4. Conclusions

The paper aimed to test different specifications of production functions in a CGE model. In particular, the model has been expanded with different modules to better represent Nitrogen and Phosphorus producing sectors (i.e. representation of organic fertilisers and general improvement in structuring the livestock production system) in order to assess the implications of the implementation of a quantity preserving function instead of a regular CES function for products that have a relevant physical quantity associated. In this case, the focus was tailored on organic and chemical fertilisers and their Nitrogen and Phosphorus footprint, as they are critical elements of the planetary system as well as two key planetary boundaries. The paper shows that the two different types of production structures lead to a significant difference in the results. As such, the choice between the two options could significantly influence the political choices assessed through modelling. Therefore, the paper concludes that implementing a quantity preserving function is recommended when dealing with physical quantities and variables that need particular attention with regard to the physical values they rely on, as they have a significant for both the environment and their repercussions in the political arena.

References

Brown, C. (2021). *Available Nutrients and Value for Manure from Various Livestock Types - OMAFRA 21-077*.

de Vries, W., Kros, J., Kroeze, C., & Seitzinger, S. P. (2013). Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. *Current Opinion in Environmental Sustainability*, *5*(3), 392–402. https://doi.org/https://doi.org/10.1016/j.cosust.2013.07.004

Dixon, P. B., & Rimmer, M. T. (2006). The displacement effect of labour-market programs: MONASH analysis. *Economic Record*, *82*(SPEC. ISS. 1). https://doi.org/10.1111/j.1475-4932.2006.00330.x

Foley, J. (2010). Boundaries for a Healthy Planet. *Scientific American*, *302*(4), 54–57. https://doi.org/10.2307/26001979

Fujimori, S., Hasegawa, T., Masui, T., & Takahashi, K. (2014). Land use representation in a global CGE model for long-term simulation: CET vs. logit functions. *Food Security*, *6*(5), 685–699. https://doi.org/10.1007/s12571-014-0375-z

Gatto, A., Kuiper, M., & van Meijl, H. (2023). Economic, social and environmental spillovers decrease the benefits of a global dietary shift. *Nature Food*, *4*(6), 496–507. https://doi.org/10.1038/s43016-023-00769-y

Giesecke, J. A., Tran, N. H., Corong, E. L., & Jaffee, S. (2013). Rice Land Designation Policy in Vietnam and the Implications of Policy Reform for Food Security and Economic Welfare. *Journal of Development Studies*, *49*(9), 1202–1218. https://doi.org/10.1080/00220388.2013.777705

Kuiper, M., de Lange, T., van Zeist, W. J., & van Meijl, H. (2025). Exploring environmental and distributional impacts of different transition pathways for healthier and sustainable diets – an economic modelling study. *Lancet Planetary Health, in Process.*

Lenzen, M., Geschke, A., West, J., Fry, J., Malik, A., Giljum, S., Milà i Canals, L., Piñero, P., Lutter, S., Wiedmann, T., Li, M., Sevenster, M., Potočnik, J., Teixeira, I., Van Voore, M., Nansai, K., & Schandl, H. (2021). Implementing the material footprint to measure progress towards Sustainable Development Goals 8 and 12. *Nature Sustainability*, *5*(2), 157–166. https://doi.org/10.1038/s41893-021-00811-6

Peñuelas, J., & Sardans, J. (2022). The global nitrogen-phosphorus imbalance. *Science*, *375*(6578), 266–267. https://doi.org/10.1126/science.abl4827

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J. C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., … Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change*, *42*, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., Von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., … Rockström, J. (2023). *Earth beyond six of nine planetary boundaries*. https://www.science.org

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., De Wit, C. A., Hughes, T., Van Der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., … Walker, B. (2009). *Planetary Boundaries: Exploring the Safe Operating Space for Humanity* (Vol. 14, Issue 2). https://about.jstor.org/terms

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., De Vries, W., De Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223). https://doi.org/10.1126/science.1259855

Stehfest, E., van Vuuren, D., Kram, T., Bouwman, L., Alkemade, R., Bakkenes, M., Biemans, H., Bouwman, A., den Elzen, M., Janse, J., Lucas, P., van Minnen, J., Müller, M., & Prins, A. (2014). *Integrated Assessment of Global Environmental Change with IMAGE. Model description and policy applications.*

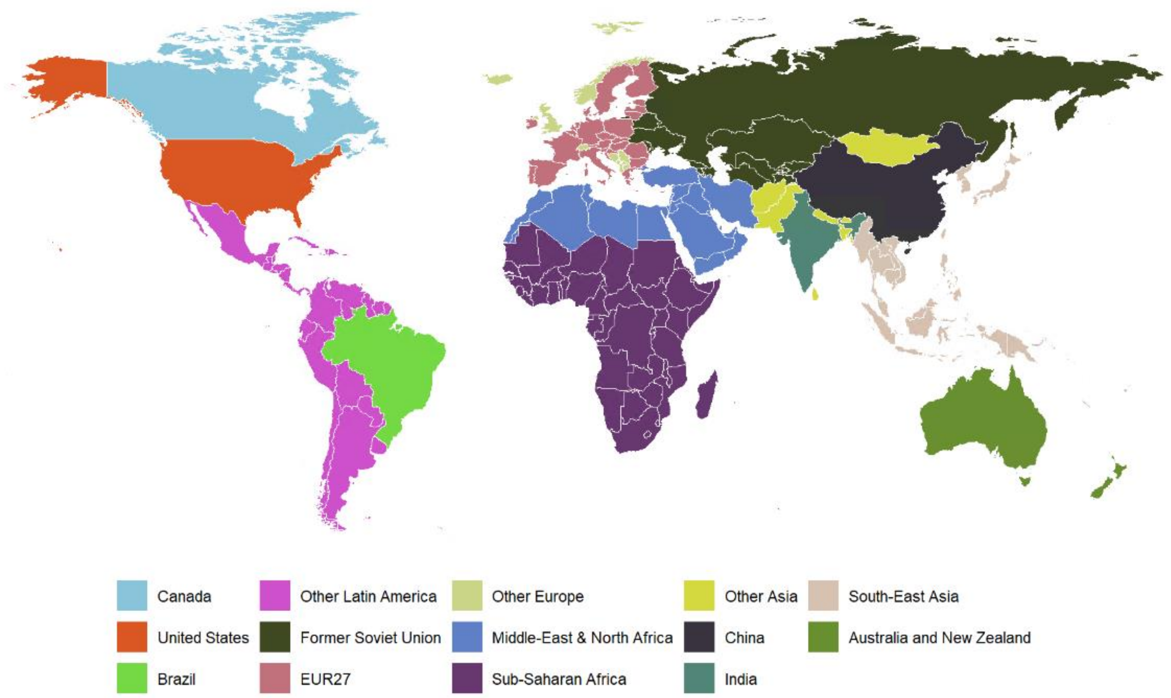
Van Der Mensbrugghe, D., & Peters, J. C. (2016). Volume preserving CES and CET formulations. *19th Annual Conference on Global Economic Analysis*.

Woltjer, G. B., Kuiper, M., Kavallari, A., van Meijl, H., Powell, J. P., Rutten, M. M., Shutes, L. J., & Tabeau, A. A. (2014). *The MAGNET Model: Module description* (Vols. 14–57). LEI.

Supplementary Information.

Section 1. Figures and Tables.

F1. Regional Aggregation in MAGNET



T1. Sectoral Aggregation in MAGNET

Commodity	Description	Disaggregated MAGNET sets	Mapped GTAP sets	Common Name
aqcltr	Aquaculture	Diad, Fresh, Crust, Marin, Molus	fsh, fsh, fsh, fsh, fsh	Aquaculture
b_t	Beverages and tobacco products	b_t	b_t	Beverages and tobacco products
bf2nd	2nd gen biofuel	ftfuel, eth	p_c, p_c	
bfmt	beef meat	BFCMT	cmt	Beef meat
Bgas	Biogas	Bgas	gdt	
bioch	bio chemicals	bioch	chm	biochemicals
biod	Biodiesel	biod, bf_o	p_c, p_c	Biodiesel
bioe	bioelectricity 2nd gen	bioe	ely	bioelectricity 2nd gen
biog	Biogasoline	biog, bf_g, bf_s, bf_m	p_c, p_c, p_c, p_c	Ethanol
bioh	bioheat	bioh	ely	bioheat

biom	biomass from compost and bioe	biom	omf	biomass for compost and bioe
bioph	bio pharmaceuticals	bioph	bph	biopharmaceuticals
biopl	bio plastics	lsug, pe, pla, bfchem, biopl	sgr, chm, chm, chm, rpp	bioplastics
bph	Basic pharmaceutical products	bph	bph	Basic pharmaceutical products
cattle	cattle sector	bfctl	ctl	cattle
chm	Chemical products	chm, f_chem	chm, chm	Chemical products
coa	Coal	coa	coa	Coal
comp	composting	comp	omf	Composting
crops	Crops nec	ocr, r_ocr	ocr, ocr	Crops
cvol	Crude vegetable oil	cvol	vol	Crude vegetable oil
dairy	Dairy products	mil	mil	Dairy products
ddgs	Biogasoline byproduct	ddgs	p_c	Distiller dried grains and solubles
dwe	Dwellings	dwe	dwe	dwellings
edu	Education	edu	edu	Education
ely	ely	ely	ely	Electricity
ely_c	electricity from coal	ely_c	ely	electricity from coal
ely_g	electricity from gas	ely_g	ely	electricity from gas
ely_h	electricty from hydro	ely_h	ely	electricity from hydro
ely_n	electricty from nuclear	ely_n	ely	electricity from nuclear
ely_w	electricty from wind and solar	ely_w	ely	electricity from wind and solar
elydist	Electricity distribution	edt	ely	
fdctl	feed cattle	feed, fdctl	ofd, ofd	Cattle feed (suitable for all ruminants)
fdfsh	feed fish	fdfsh	ofd	Fish feed
fdpig	feed pigs	fdpig	ofd	Pig feed
fdplt	feed poultry	fdplt	ofd	
fert_k	fertilizer nutrient k	fert_k	chm	Potassium fertilizer
fert_n	fertilizer nutrient n	fert_n	chm	Nitrogen fertilizer
fert_p	fertilizer nutrient p	fert_p	chm	Phosphorus fertilizer
fishm	fish meal	fishm	ofd	Fishmeal
fishp	Fish processing	Fishp	ofd	Processed fish
foodserv	Food services	afs, osg, hht	afs, osg, hht	Food services

frs	Forestry	frs	frs	Forestry and wood processing
fruit	Fruit	fruit, r_frt	fruit, fruit	Fruit
gas	Gas	gas	gas	Fossil gas
gas_dist	Gas manufacture, distribution	gdt	gdt	Gas distribution
grain	Cereal grains nec	gro	gro	Cereal grains nec
heat	heat	heat	ely	Heat
incin	incineration	incin	ome	Incineration
landf	landfilling	landf	ome	Landfilling
Lfgas	Lfgas	Lfgas	ome	
manu	Manufacturing	i_s, nfm, fmp, ele, eeq, ome, mvh, otn, cns	i_s, nfm, fmp, ele, eeq, ome, mvh, otn, cns	Manufacturing
milk	Raw milk	rmk	rmk	Milk
mnbctl	manure beef cattle	mnbctl	ctl	
mnctl	manure cattle	mnctl	ctl	
mnoap	manure other animals	mnoap	oap	
mnpltry	manure poultry	mnpltry	oap	
mnrmk	manure rawmilk	mnrmk	rmk	
mola	Molasse	mola	sgr	Molasse
nmm	Mineral products nec	nmm	nmm	Mineral products nec
nuts	Nuts	nuts, r_nuts	nuts, nuts	Nuts
oagr	Other agriculture	pfb	pfb	Other agriculture
ofd	Processed food	ofd	ofd	Processed food
oil	Crude oil	oil	oil	Crude oil
oilcake	Oil cake byproduct of cvol used as animal feed	oilcake	vol	Oilcake
oils	Oil seeds	osd	osd	Oil seeds
omf	Other Manufacturing, includes furniture	omf	omf	Manufactures nec
othcmt	Meat: other cattle,sheep,goats ,horse	cmt	cmt	Other cattle meat
othctl	sheep,goats,horse s	ctl	ctl	Other cattle
othmt	Other meat product nec	omt	omt	Other meat
oxt	Minerals nec	oxt	oxt	Minerals nec
p_c	Petroleum, coal products	p_c, aviaf, ftavia	p_c, p_c, p_c	
pagl	recycled paper and glass	pagl	omf	recycled paper and glass
pcr	Processed rice	pcr	pcr	Processed rice

pdr	Paddy and processed rice	pdr	pdr	Paddy and processed rice
pest	pesticides	pest	chm	
pigpls	Pig and other animal product	oap	oap	Pig Poultry
plan	Plantation	plan	frs	Plantation
pltry	poultry sector	pltry	oap	Poultry
ppp	Paper products, publishing	ppp	ppp	Paper & Paper Products
pulmt	poultry meat	poum	omt	poultry meat
pulses	Pulses	pulses, r_puls	pulses, pulses	Pulses
r_frs	residue frs	r_frs	frs	residue frs
r_gro	residue gro	r_gro	gro	residue gro
r_osd	residue osd	r_osd	osd	residue osd
r_pdr	residue pdr	r_pdr	pdr	residue pdr
recy	Recycling	recy	omf	recycling
respel	residue and pellets	res, pel	p_c, lum	
roots	Roots and tubers	roots, r_root	roots, roots	Roots and tubers
ros	Recreational and other service	ros	ros	Recreational and other service
rpp	Rubber and plastic products	rpp	rpp	Rubber and plastic products
ser	Services	wtr, trd, whs, cmn, ofi, ins, rsa, obs	wtr, trd, whs, cmn, ofi, ins, rsa, obs	Services
sug	Sugar cane, sugar beet	c_b	c_b	Sugar cane, sugar beet
sugar	Sugar	sgr, SugSc	sgr, ofd	Sugar and molasses
Swd	Seaweed	Swd	fsh	
texplus	textiles, leather and wearing apparel	tex, wap, lea	tex, wap, lea	Textiles
trans	Transport sector	otp, wtp, atp	otp, wtp, atp	Transport sector
veg	Vegatables	v_f, veg, r_v_f, r_veg	v_f, veg, v_f, veg	Vegetables
vol	Vegetable oils and fats	vol	vol	Vegetable oils and fats
WCG	waste collection green waste	WCG	osg	waste collection green
WCGP	Waste collection glass paper	WCGP	osg	Waste collection glass paper
WCR	Waste Collection rest waste	WCR	osg	waste collection rest
wely	energy from waste	wely	ome	energy from waste
wfish	Wild fish	fsh	fsh	Wild Fish

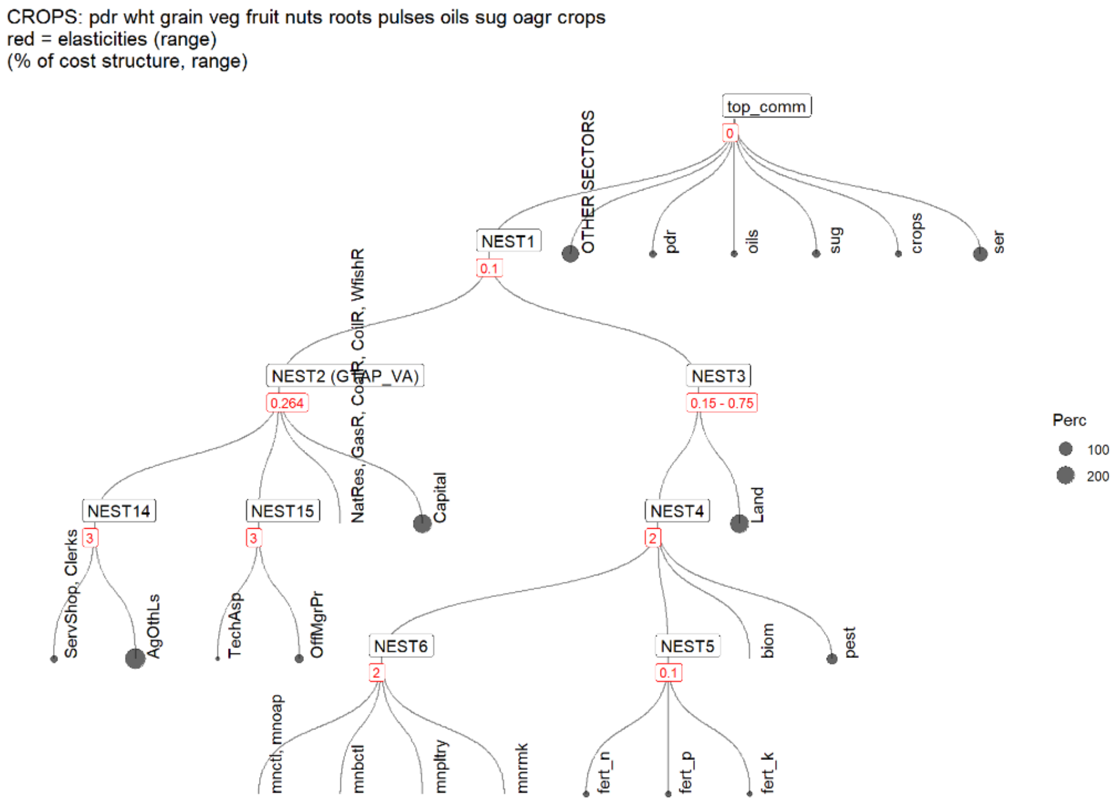
wht	Wheat	wht, r_wht	wht, wht	Wheat
wol	Wool, silk-worm cocoons	wol	wol	Wool
wood	Wood products	lum	lum	wood

T2. Mapping of activities in MAGNET with additional data sources

MAGNET name	MAGNET code	OECD Livestock	Brown (2021) Livestock
Dairy	Rmk	Beef (splitted)	Dairy
Other cattle	Othctl	Sheep, goats, horses	Sheep, Horses
Beef cattle	Bfctl	Beef (splitted)	Beef, veal
Pigs	Pigpls	Pigs	Hogs
Poultry	Pltry	Poultry	Chicken, Turkeys

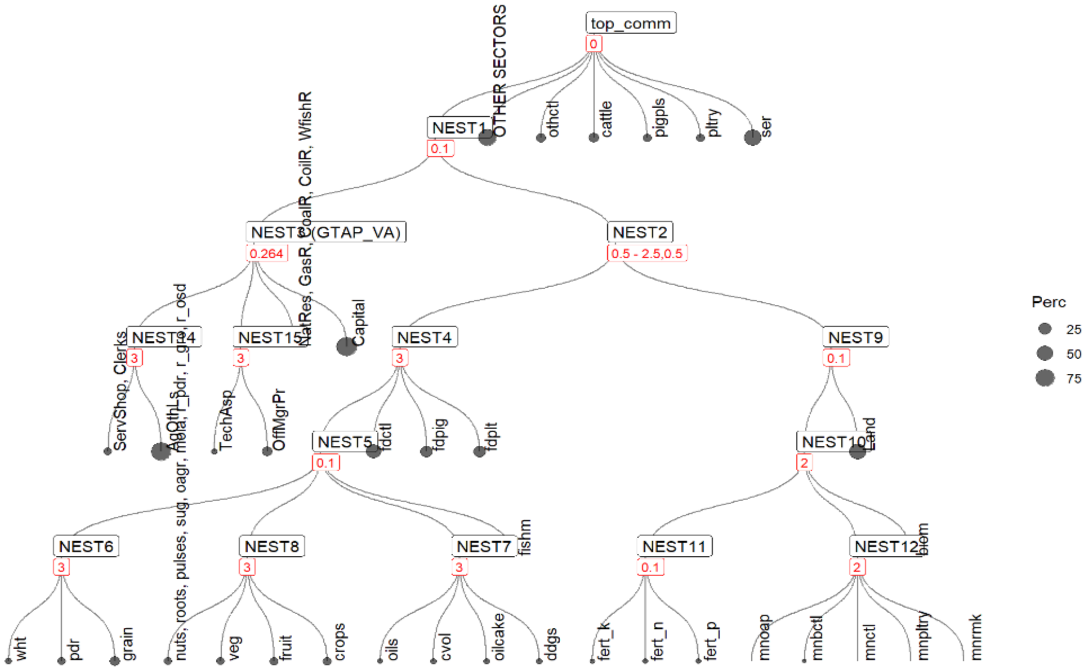
F2. Crop, Livestock and Biogas production structures in MANGET

2.1 Crops



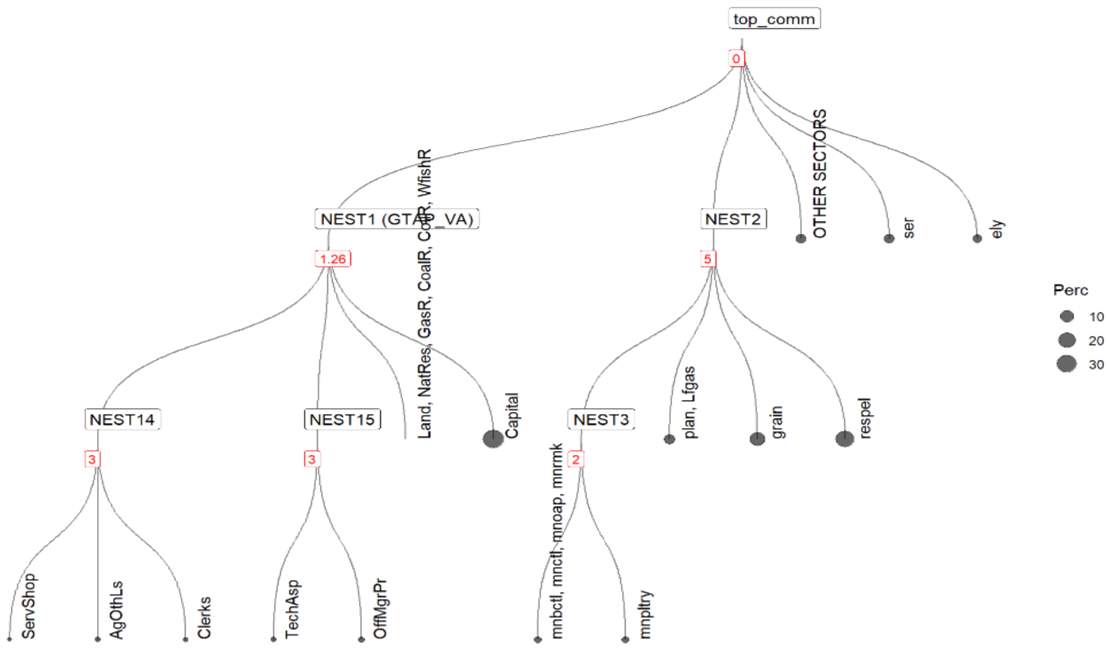
2.2 Livestock

LVSTCK: othctl cattle pigpls pltry milk wol
red = elasticities (range)
(% of cost structure, range)



2.3 Biogas

BIOGAS: Bgas
red = elasticities (range)
(% of cost structure, range)



Section 2. Code modifications to implement the quantity preserving production function.

Changes magnet code: sets and coefficients

```
Set Q_source # Commodities which are producing Nitrogen and Phosphorus #
   read elements from file MCHOICE header "SQNT";

 Coefficient (all,i,Q_source)(all,r,DREG)
 DQQNT(i,r) # Quantity of nutrient production #;
 Read DQQNT from file MCHOICE header "QQNT";

Coefficient (all,i,Q_source)(all,m,REG) QQNT(i,m);
 Formula (all,i,Q_source)(all,m,REG)
 QQNT(i,m) = sum(r,DREG:DREG2REG(r) = m,DQQNT(i,r));

Write(set) Q_source to file SETS header "SQNT";
 Write QQNT to file DATA header "QQNT";
```

Changes magnet code: production trees data and sets
Its implementation include the following steps:

a) Define the variables used by the quantity preserving CES function to define the physical quantities that need to be used for calibration:

```
Coefficient (all,i,FIRM_COMM)(all,j,ACTS)(all,r,REG)
 QQNT(i,j,r) # Quantity of PNK nutrient production #;

Formula(initial)(all,i,FIRM_COMM)(all,j,ACTS)(all,r,REG)
 QQNT(i,j,r)=0+If(i in Q_source,DQQNT(i,r)
             *VFP(i,j,r)/ID01[sum{k,ACTS,VFP(i,k,r)}]);
 Update(all,i,FIRM_COMM)(all,j,ACTS)(all,r,REG)
 QQNT(i,j,r)=qfa(i,j,r);
 set nQ_source= COMM-Q_source;
 Coefficient (all,d,FIRM_COMM)(all,a,ACTS)(all,r,REG)
    QFP(d,a,r);
 formula(all,d,FIRM_COMM)(all,a,ACTS)(all,r,REG)
    QFP(d,a,r)=QQNT(d,a,r);
```

b) The quantity preserving nests, i.e. the nodes of production that need to preserve quantities, need to be identified.

```
Set NNNO
  Read elements from file MODPARM1 header "NNNO";
Set NNNO1 #Subproducts used in sector 1#
      = NNNO intersect SUBPR_COMM;
Set NOUP
  Read elements from file MODPARM1 header "NOUP";
Set NOUP1 #Subproducts used in sector 1#
        = NOUP intersect SUBPR_COMM;
Set NODW
  Read elements from file MODPARM1 header "NODW";
Set NODW1 #Subproducts used in sector 1#
        = NODW intersect SUBPR_COMM;
```

c) the quantity preserving nests are identified based on the set "Q_source", i.e. the sets that we want to be quantity preserving. Note that the quantity preserving CES function can only be used if quantity data is available. It is however possible to have a mixed production tree with some nests using quantity preserving CES function and some nest using a normal CES function. For the crop and livestock sectors we have implemented the quantity preserving CES function for only part of the production tree namely the manure and fertilizer nests. All other nests in these trees are still normal CES nests.:

```
Coefficient (all,i,Q_source)(all,j,NNNO1)(all,k,CESACTS)
  QPCESNS(i,j,k);
Formula (all,i,Q_source)(all,j,NNNO1)(all,k,CESACTS)
  QPCESNS(i,j,k) = CESNESTSTRUC(i,j,k);
Set Reltrees
 = (all, i, CESACTS:sum{j,Q_source,sum{k,NNNO1,QPCESNS(j,k,i)}}>0);
Set QPNESTS
 = (all, i, NNNO1:sum{j,Q_source,sum{k,Reltrees,QPCESNS(j,i,k)}}>0);
Set NQPNESTS = NNNO1 - QPNESTS;
```

d) The nests are mapped to each other to single out which ones need to be quantity preserving:

```
coefficient (parameter) (all,i,NOUP1) MAP_ORDER2(i);
 Formula (initial) (all,i,NOUP1) MAP_ORDER2(i) = $POS(i) ;
 Mapping (ONTO) NOUP12NNNO1 from NOUP1 to NNNO1;
 Formula (all,c,NOUP1) NOUP12NNNO1(c) = ROUND(MAP_ORDER2(c));
coefficient (parameter) (all,i,NODW1) MAP_ORDER3(i);
 Formula (initial) (all,i,NODW1) MAP_ORDER3(i) = $POS(i) ;
 Mapping (ONTO) NODW12NNNO1 from NODW1 to NNNO1;
 Formula (all,c,NODW1) NODW12NNNO1(c) = ROUND(MAP_ORDER3(c));

 set QP1 = QPNESTS intersect NOUP1;
Coefficient (all,i,NODW1)(all,r,Reltrees) QP2C(i,r);
Formula (all,i,NODW1)(all,r,Reltrees)
 QP2C(i,r) = 0 +  IF(sum{j,Q_source,QPCESNS(j,NODW12NNNO1(i),r)}>0,1);
Coefficient (all,j,NNNO1)(all,r,Reltrees) QP3C(j,r);
Formula (all,j,NNNO1)(all,r,Reltrees)
QP3C(j,r) = 0 +  IF(sum{i,Q_source,QPCESNS(i,j,r)}>0,1);
set NPDW = NODW1 union NNNO1;
 subset NPDW is subset of SUBPRT_COMM;
Coefficient (all,j,SUBPRT_COMM)(all,r,Reltrees) QP4C(j,r);
Formula (all,j,NNNO1)(all,r,Reltrees) QP4C(j,r) = QP3C(j,r);
Coefficient (all,j,NODW1)(all,r,Reltrees) QP5C(j,r);
Formula (all,j,NODW1)(all,r,Reltrees) QP5C(j,r) = QP4C(j,r);
Coefficient (all,j,NODW1)(all,r,Reltrees) QP6C(j,r);
Formula (all,j,NODW1)(all,r,Reltrees) QP6C(j,r) = 0 + IF(QP5C(j,r)>1,1);
set QP2= (all, i, NODW1:sum{k,Reltrees,QP6C(i,k)}>1);
set QP3 = QPNESTS intersect QP2;

Coefficient (all,i,ACTS) (all,j,Reltrees)
  CESSECTQP(i,j) # Allocation of sectors to strcutures #;
Formula (all,i,ACTS) (all,j,Reltrees)
  CESSECTQP(i,j) = CESSECTALLOC(i,j);

Set SETQP =(all,i,ACTS:sum{k,Reltrees,CESSECTQP(i,k)}>0);
set cro3=(all,i,ACTS:CESSECTALLOC(i,"Crops")>0);
set ani3=(all,i,ACTS:CESSECTALLOC(i,"Lvstck")>0);
set bgas1=(all,i,ACTS:CESSECTALLOC(i,"BIOGAS")>0);
```

e) a matrix of quantity and non-quantity preserving nests and products is created:

```
Coefficient(all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  NQUANT_M(i,j,r);
 Formula (all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  NQUANT_M(i,j,r)=1;
 Coefficient(all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  QUANT_M(i,j,r);
 Formula(all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  QUANT_M(i,j,r)=0;
 Formula(all,i,Q_source)(all,j,SETQP)(all,r,CETPROD_REG)
  QUANT_M(i,j,r)=1;
 Formula (all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  NQUANT_M(i,j,r)=  NQUANT_M(i,j,r)-QUANT_M(i,j,r);
Coefficient(all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  Nest_other(i,j,r);
 Formula(all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  Nest_other(i,j,r)=1;
 Coefficient(all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  Nest_QP(i,j,r);
 Formula(all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  Nest_QP(i,j,r)=0;
Formula(all,i,QPNESTS)(all,j,SETQP)(all,r,CETPROD_REG)
  Nest_QP(i,j,r)=1;
 Formula(all,i,FIRM_COMM)(all,j,ACTS)(all,r,CETPROD_REG)
  Nest_other(i,j,r)=1-Nest_QP(i,j,r);
```

f), the structure of production is modified to account for either quantity preserving or value preserving CES functions. In particular the price of intermediate production is modified as:

```
pfa(i,j,r)=
 IF(i in SUB15_@S,
   nest_other(i,j,r)*sum(k,INP15_@S,
     CSINP15_@S(k,j,r) * [pfa(k,j,r) - afa(k,j,r)])
   +Nest_QP(i,j,r)*(sum(k,INP15_@S,
     CSINP15_@S(k,j,r)*(pfa(k,j,r)+qfa(k,j,r)))-qfa(i,j,r)))
```

While the quantity of intermediate demand form firms is modified as:

```
qfa(i,j,r)=0*time+
 IF(i in INP15_@S,
          NQUANT_M(i,j,r)
          *(- afa(i,j,r) + sum{k,SUB15_@S,qfa(k,j,r)}
          - sum{k,SUB15_@S,EL_PROD(k,j,r)}
          * [pfa(i,j,r) - afa(i,j,r) - sum{k,SUB15_@S,pfa(k,j,r)}])
          +IF(QFP(i,j,r)>=0,QUANT_M(i,j,r)
          *(sum{k,SUB15_@S,qfa(k,j,r)}
          - sum{k,SUB15_@S,EL_PROD(k,j,r)}
          *[pfa(i,j,r)-sum{k,INP15_@S,QCSINP15_@S(k,j,r)*pfa(k,j,r)}])))
```

This structure ensures that if a commodity is produced by a quantity preserving nest or has positive quantities in the preserving value header, it will adopt the second part of the equations, i.e. the quantity preserving functions.