



Expanding capabilities for policy evaluation through deep learning emulation of CGE models

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CGE emulators rationale

- Fast
 - Open up possibilities to real-time modelling
 - Facilitate multi-model integration
 - Enable large-scale sensitivity analyses
 - Model calibration
- Open source – to train and use
- Lowering barriers to entry
 - PANAP experience: CGE learning curve too steep for practitioners
 - Many policy questions require fast answers
 - Results can be explored through interactive visualisation tools

Objectives

Use case

- Develop a reliable emulator that covers many policy questions
- Open up emulator for interaction to non-technical users

Technical

- Determine the neural network design that maximises emulator performance
- Address the 'black box' issue by allowing many CGE results to be emulated and explored simultaneously

Methods – overview

Design

- Emulation of single-country CGE model (DEMETRA for Kenya) using a feedforward multi-layer perceptron (MLP)
- 100/140 policy instruments (inputs)
- 79 trade elasticities for Monte Carlo analysis
- 1612 CGE result elements (outputs)

Process

- Neural network fine-tuning using multi-objective evolutionary algorithms
- 100 000 sample size – 80/20 split of training and testing
- ‘Sensitivity dataset’ as out-of-sample – testing the emulator performance for each policy instrument individually

CGE policy instruments

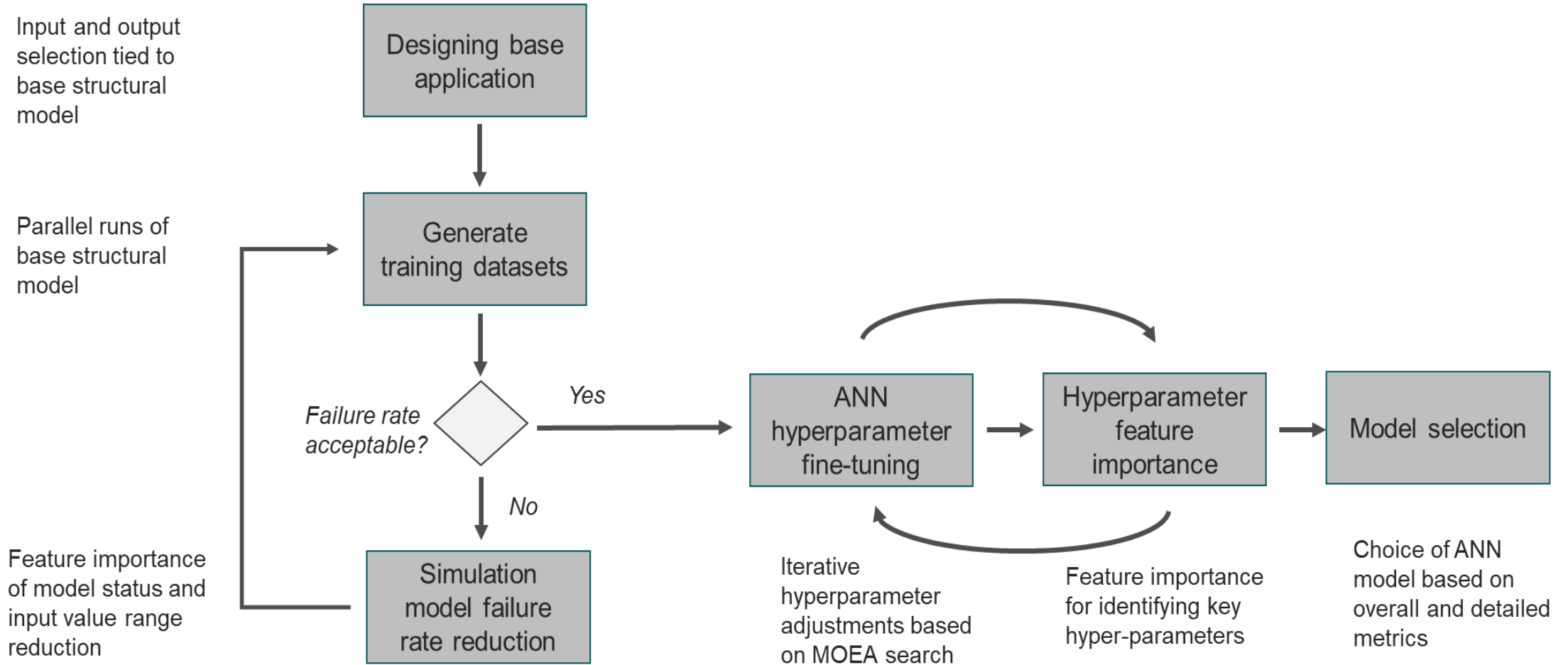
Policy instrument	Domain	Sub-domains (cardinality)
Foreign direct investment (FDI) changes	Investment	General (1)
Export demand shifts	International Trade	By export commodity (39)
Trade margins change	Domestic Trade	Distinct trade margins for agrifood and manufacturing (2)
Productivity growth	Production	By factor of production (labour, capital, land) and by macro-sector (agrifood, manufacturing, service) (7)
Government spending changes	Public spending	By commodity group relevant to public spending (36)
General sales tax change	Taxation	By macro-commodity: agrifood, manufacturing, services (3)
Targeted consumer subsidies reform	Taxation	Distinct commodities: food (maize, wheat, rice, other grains, milled grains), fertilizer, petroleum products (7)
Corporate tax reform	Taxation	General (1)
Income tax reform	Taxation	General (1)
Factor use tax reform	Taxation	By factor (labour, capital and land) (3)
Tariffs	Taxation	By import commodity (40)

- The initial model was trained for first 100 instruments
- Tariffs (last 40 instruments) added in a second stage

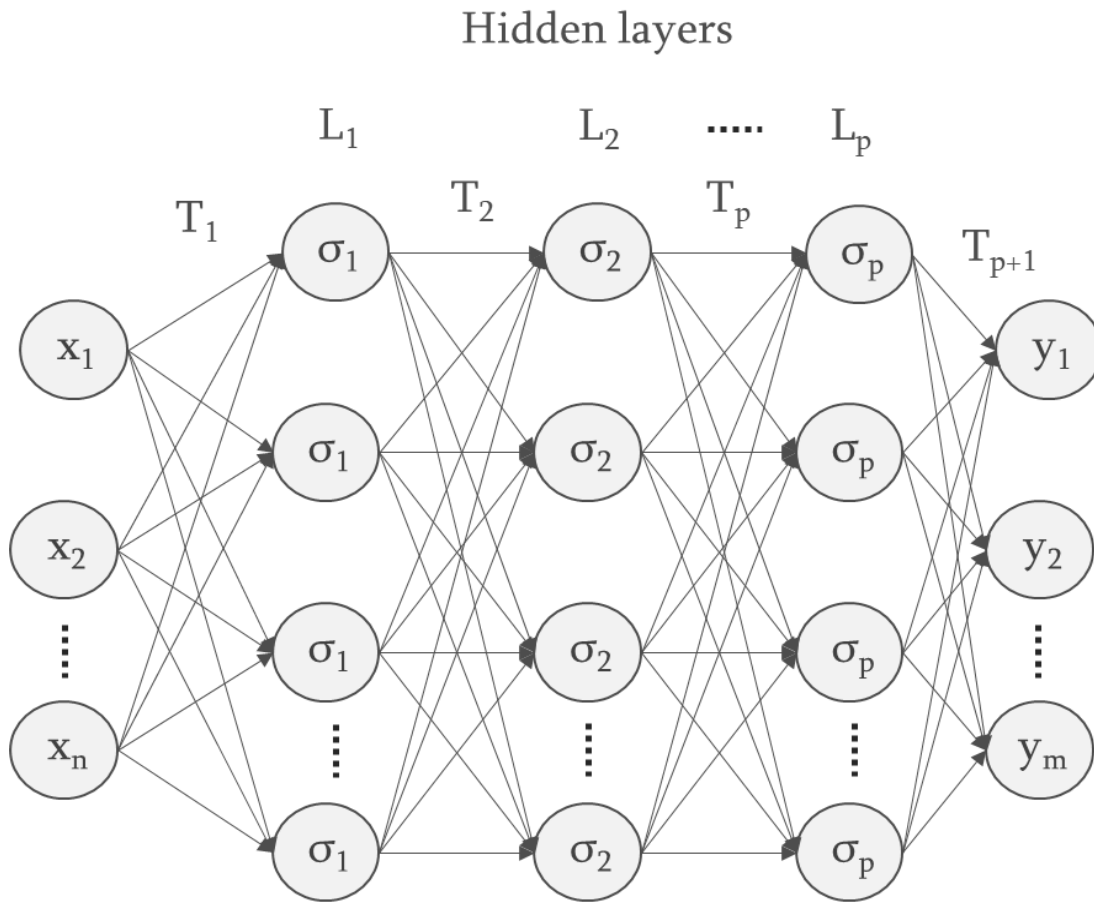
Emulated CGE outputs

Output	Category	Cardinality
Gross Domestic Product (RGDP)	Scalar	1
Consumer Price Index (CPI)	Scalar	1
Exchange rate (ERX)	Scalar	1
Government income (YG)	Scalar	1
Value added by sector (VVA)	Value	51
Output by sector (QX)	Quantities	51
Exports by commodity	Prices (PE)	39
	Quantities (QE)	39
Imports by commodity (QM)	Quantities	40
Domestic supply	Prices (PD)	71
	Quantities (QD)	71
Consumer demand by commodity and by household	Quantities (QCD)	1025
Factor demand by sector	Quantities (FD)	221
Total		1612

Emulator fine-tuning workflow



Emulator fine-tuning



$$N(x) = T_{p+1} * \sigma_p * T_p * \sigma_{p-1} * \dots * T_2 * \sigma_1 * T_1(x)$$

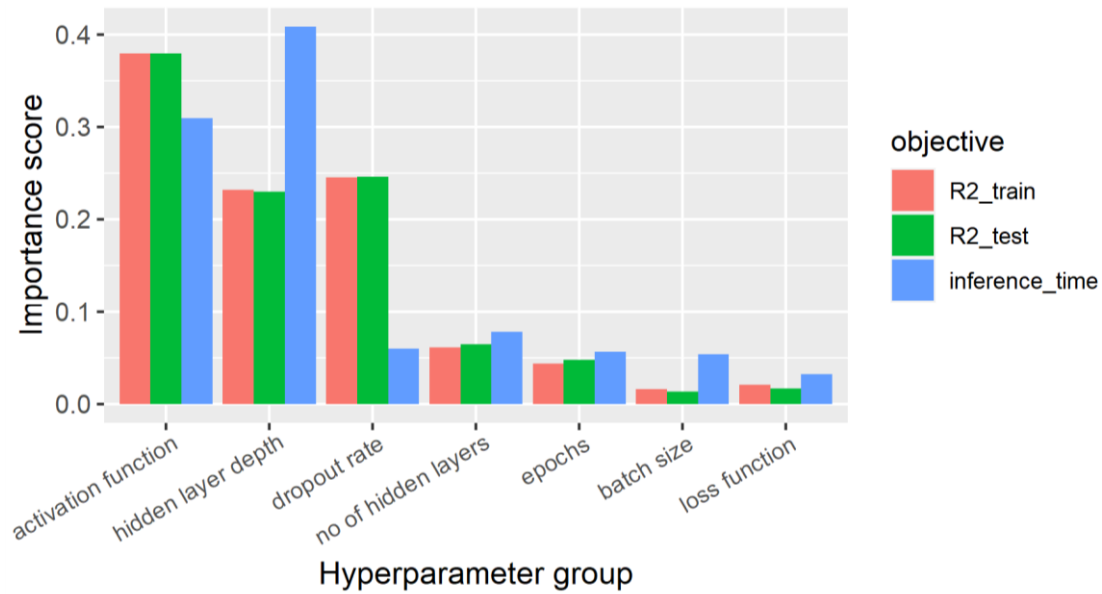
$$T_i = W_i I_i + B_i$$

Hyperparameter fine-tuning

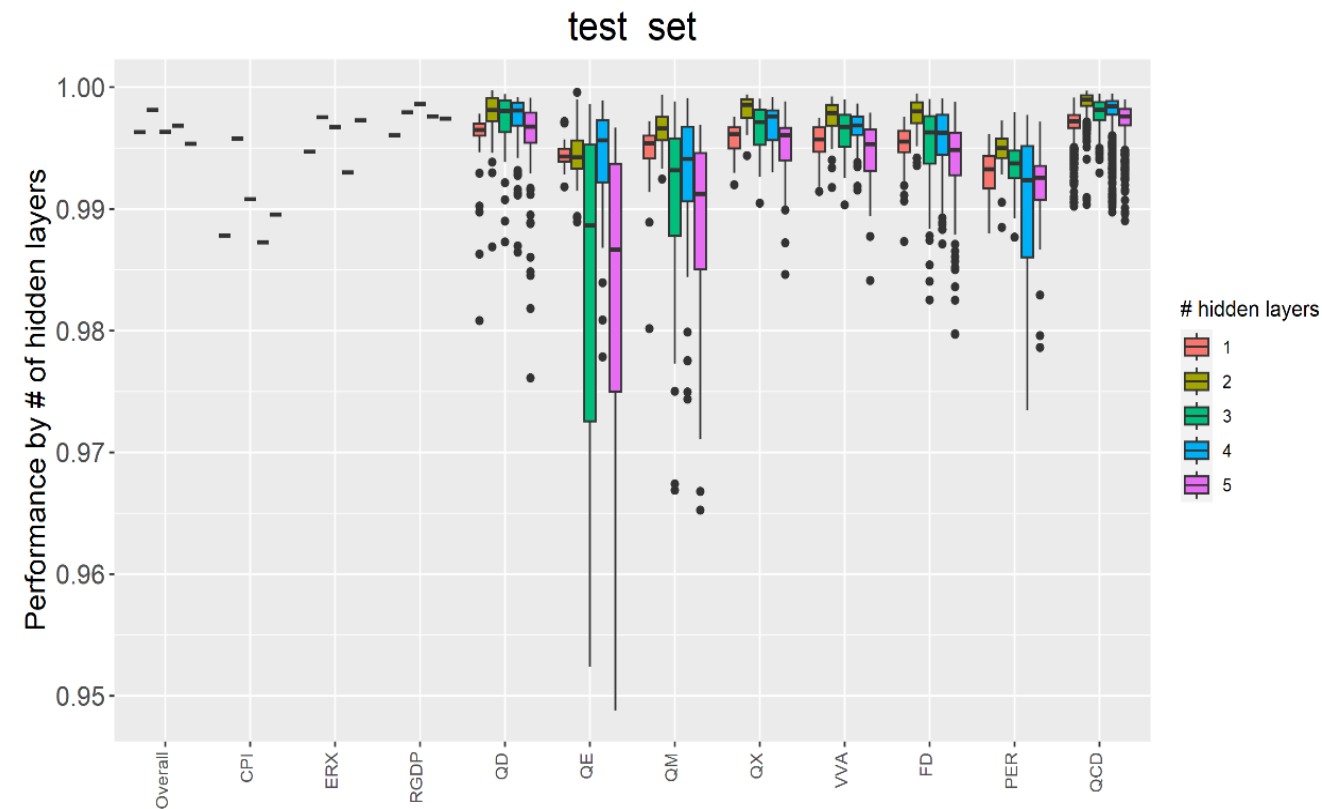
- Number of hidden layers p
- Depth of hidden layers
- Activation functions σ
- Learning rate
- Epochs
- Batch size
- Loss function
- Etc.

Fine-tuning results

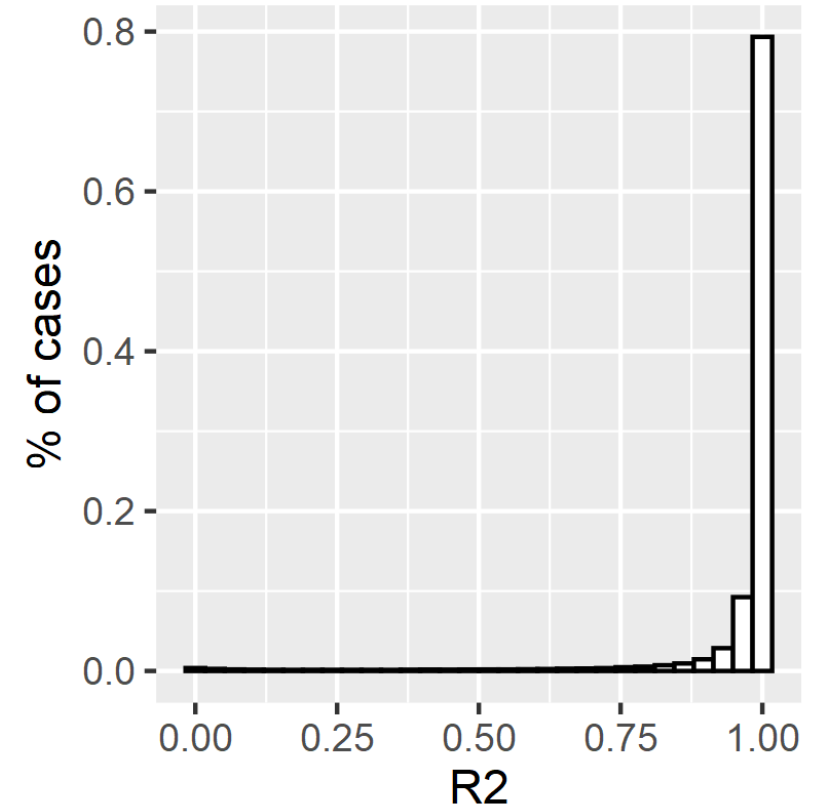
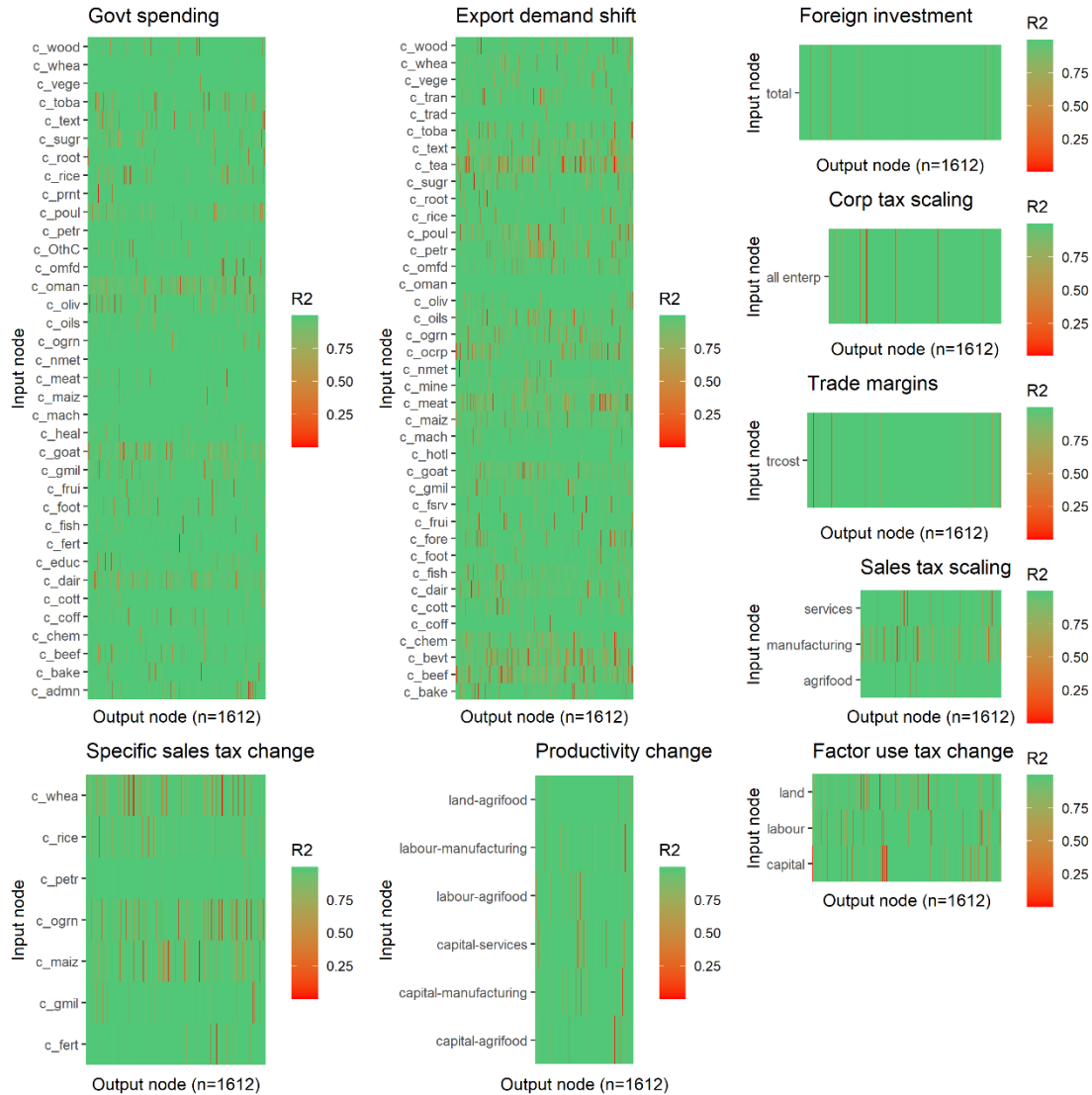
Hyperparameter feature importance



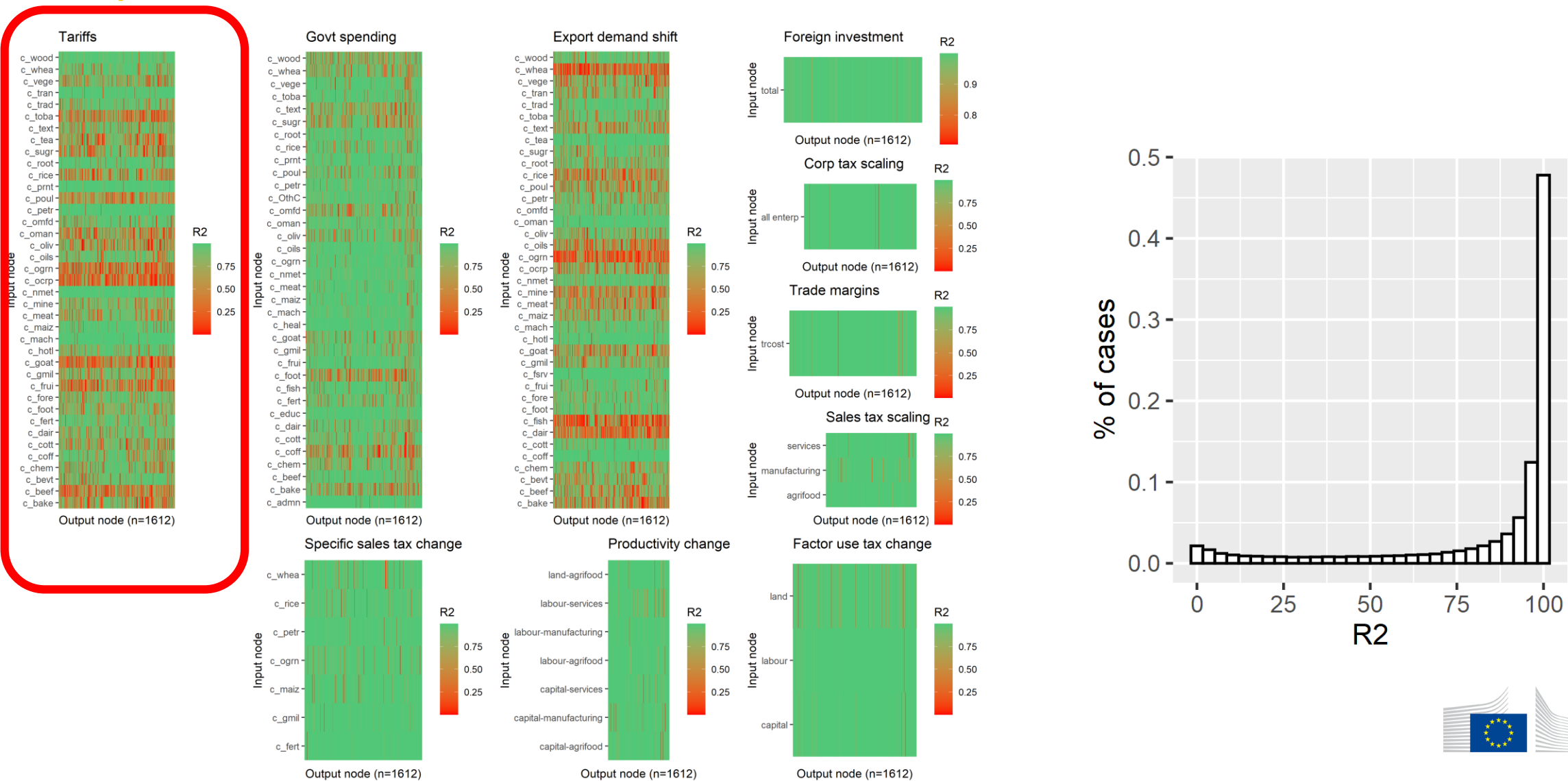
Detailed R2 performance for different # of hidden layers



R2 results – out-of-sample predictions (paired input-output for 100-inputs setup)



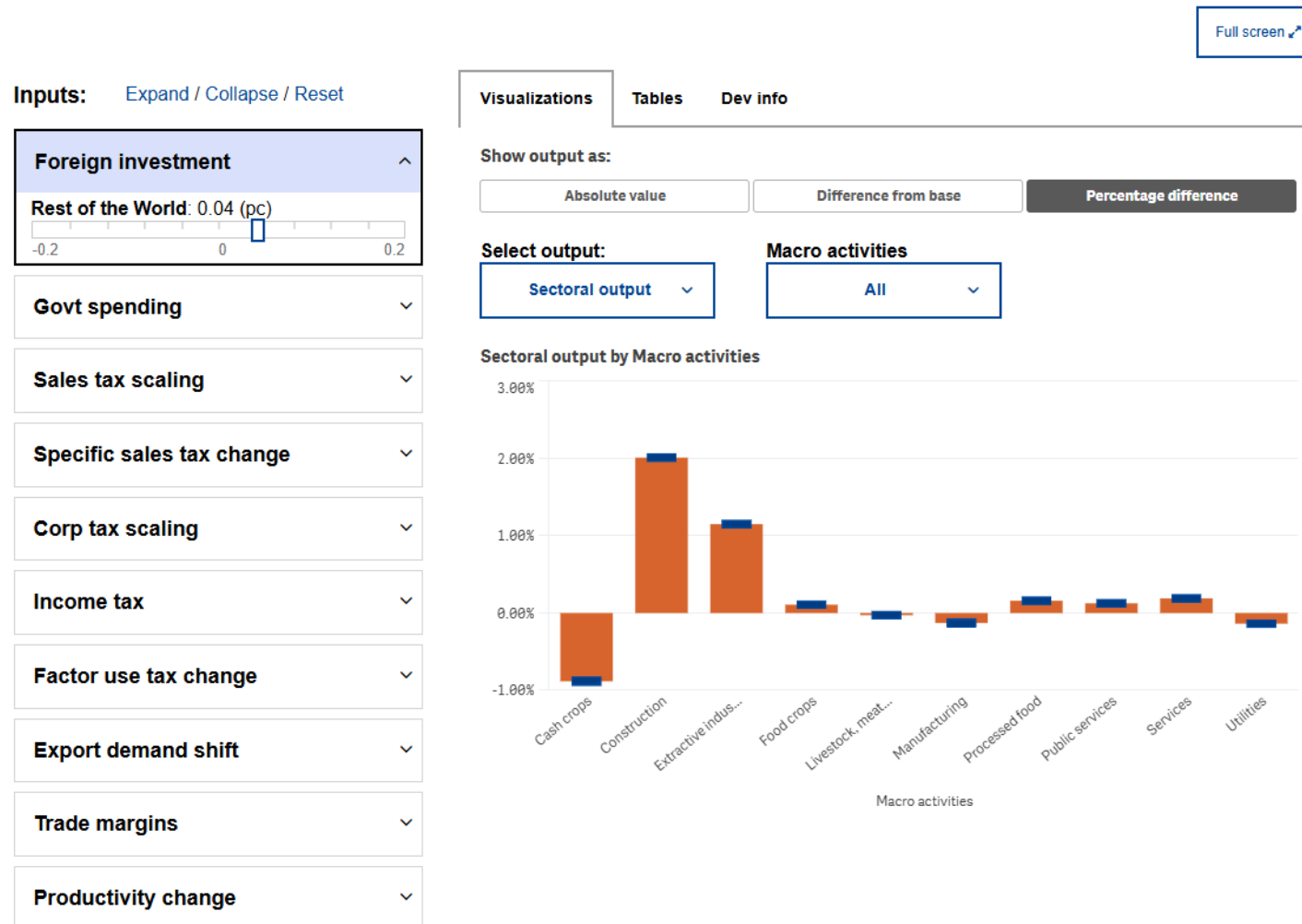
R2 results – out-of-sample predictions (paired input-output for 140-inputs setup)



Implementation in visual tool

Policy Emulator Kenya

<https://tinyurl.com/5xzh4fsw>



Take-aways

- An MLP with many inputs and outputs emulates a wide range of CGE use cases
- Multiple outputs allow for the exploration of results in detail
- MOEA search for fine-tuning leads to relatively simple MLPs with very good emulator performance
- Short inference time allows many runs for large scale sensitivity analysis
- Application design (instrument choice) should nevertheless be done carefully, notably in trade area

Thank you

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