

Introduction to Computable General Equilibrium modelling with GTAP

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Outline

- 1 Introduction to CGE
 - What is special about CGE
 - Software & technicalities
 - GTAP: model & database
- 2 Economic building blocks
 - Data: Social Accounting Matrix
 - Substitution and transformation
 - Numeraire, Walras & slacks
- 3 CGE workflow
 - Linearization
 - Closure
 - Solution
- 4 Examples
 - Food VAT reduction in DE
 - Sanctions on Russian fuels
 - Conclusion

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Computable General Equilibrium

- Multi-equation economic model.
- Multiple sectors (commodities, activities).
- GE: all markets (for each commodity, labour, capital, savings, etc.).
- Micro-founded (derived from agents' constrained optimization problems).
- Industries compete for mobile (or sluggishly moving) resources.
- Circular flow in the national economy.
- Most variables: quantities & (relative) prices.

Usual workflow with CGE:

1. Describe baseline equilibrium & calibrate elasticities.
2. Calibrate elasticities.
3. Define shock on an exogenous variables (% dev. from baseline)
4. Solve for changes of endogenous variables (% dev. from baseline)

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Software

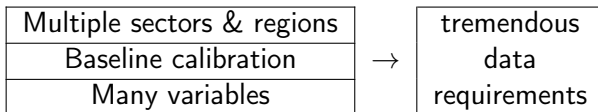
Two leading options (both commercial):

- ① **GEMPACK** (<https://www.copsmodels.com/gempack.htm>) – dominant (i.e. most widely spread models written in its native language);
CGE-focused
 - ① a bundle of programs (for editing, solving, viewing data/results)
 - ② two versions: standalone or *source* (to work with Fortran compiler)
 - ③ **RunDynam**: for recursive-dynamic models, sold separately
- ② **GAMS** (<https://www.gams.com>) – not yet dominant, but trending up; multi-purpose

Non-commercial options:

- **RunGTAP** – demo version, based on GEMPACK (limited number of models and variables per model; no model editing options), see <https://www.gtap.agecon.purdue.edu> (download after free account creation & login)
- **gEcon** – <https://gecon.r-forge.r-project.org>

GTAP



- **Global Trade Analysis Project**

(<https://www.gtap.agecon.purdue.edu>) – data provider for most CGE models worldwide
(last edition: **2014**, **65** sectors, **141** regions).

- Commercial access: **GTAPAgg2** generates a database of desired sectorial & regional aggregation.
- Some demo databases (mostly ~10 sec. & ~3 reg.) freely available with RunGTAP.

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Social Accounting Matrix (1)

To start with:

SOCIAL ACCOUNTING MATRIX		EXPENDITURES				
		<i>Production activity</i>	<i>Factors of production</i>	<i>Institutions</i>	<i>Other (exogenous)</i>	TOTAL
RECEIPTS	<i>Production activities</i>	Interindustry transactions		Consumer expenditures	Exports	
	<i>Factors of production</i>	Value added			Net factor income from abroad	
	<i>Institutions</i>		Wages and profits	Transfers and taxes	Transfers (remittances)	
	<i>Other (exogenous)</i>	Imports		Imported consumer goods		
	TOTAL					

Source:

<https://www.sciencedirect.com/topics/social-sciences/social-accounting-matrix>

Data: Social Accounting Matrix

Social Accounting Matrix (2)

When Commodities \neq Activities, Institutions = {Households, Government}, + Capital, + Margins:

	Commodities	Activities	Factors	Households	Government	Capital	Margins	Rest of World	Totals
Commodities	0	Combined Intermediate Use Matrix	0	Private Consumption	Government Consumption	Investment Consumption	Exports of Margins (fob)	Exports of Commodities (fob)	Total Demand for Commodities
Activities	Domestic Supply Matrix	0	0	0	0	0	0	0	Total Domestic Supply by Activity
Factors	0	Expenditure on Primary Inputs	0	0	0	0	0	0	Total Factor Income
Households	0	0	Distribution of Factor Incomes	0	0	0	0	0	Total Household Income
Government	Taxes on Commodities	Taxes on Production Taxes on Factor Use	Direct/Income Taxes	Direct/Income Taxes	0	0	0	0	Total Government Income
Capital	0	0	Depreciation Allowances	Household Savings	Government Savings	0	Balance on Margins Trade	Foreign Savings	Total Savings
Margins	Imports of Trade and Transport Margins	0	0	0	0	0	0	0	Total Income from Margin Imports
Rest of World	Imports of Commodities (fob)	0	0	0	0	0	0	0	Total Income from Imports
Totals	Total Supply of Commodities	Total Expenditure on Inputs by Activities	Total Factor Expenditure	Total Household Expenditure	Total Government Expenditure	Total Investment	Total Expenditure on Margin Exports	Total Expenditure on Exports	

Source: Scott McDonald & Sherman Robinson & Karen Thierfelder (2007):
Globe: A SAM Based Global CGE Model using GTAP Data

What is data used for?

- **Econometric models:** to estimate parameters
 - **DSGE models:** nothing or to fine-tune parameter values (Bayesian estimation)
 - **Input-output models:** to build (calibrate) Leontief matrix, i.e. all parameters
 - **CGE models:**
 - to represent the *baseline equilibrium* (in values & levels)
 - to calibrate some parameters (baseline shares, ratios etc.)
- e.g. $Y = \alpha_0 L^{\alpha_1}$, then use Y and L (jointly with calibrated α_1) to compute α_0 ,
then with α_0 , α_1 see what happens to Y when L rises

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CES (1)

In CGEs, volume components (e.g. labour & capital, domestic & foreign commodity, primary factors and materials, etc.) are not just added together, but *aggregated* with some function. This function guides the model on what happens if one of the components becomes more/less costly and/or more/less scarce.

Constant Elasticity of Substitution (CES) aggregator:

$$QVA = \left(\sum_e SVA_e QFE_e^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

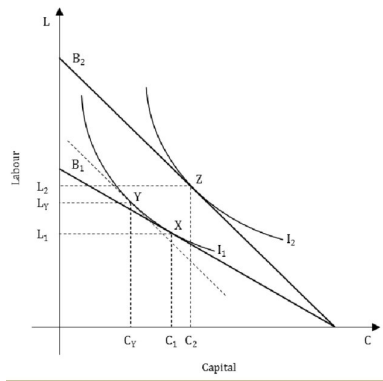
($SVA_e = \frac{QFE_e \cdot PFE_e}{\sum_e QFE_e \cdot PFE_e}$ – updatable parameter, $\sigma = ESUB^* =$ elasticity of substitution)

$$\begin{aligned} \underline{qfe_{e,kt}} &= \underline{qva_{kt}} - \underline{afe_{e,kt}} - \underline{ESUBVA_{kt}} (\underline{pfe_{e,kt}} - \underline{afe_{e,kt}} - \underline{pva_{kt}}) \\ PVA_{kt} QVA_{kt} &= \sum_e PFE_{e,kt} QFE_{e,kt} \\ pva_{kt} &= \sum_e SVA_{e,kt} (pfe_{e,kt} - afe_{e,kt}) \end{aligned}$$

13 Equation E_qfe
14 # demands for endowment commodities #
15 (all, e, ENDW) (all, a, ACTS) (all, r, REG)
16 qfe(e, a, r)
17 = - afe(e, a, r) + qva(a, r)
18 - ESUBVA(a, r) * [pfe(e, a, r) - afe(e, a, r) - pva(a, r)];

Source: Corong et al. (2017), *The Standard GTAP Model, Version 7, Journal of Global Economic Analysis*, 2(1), pp. 1-119.

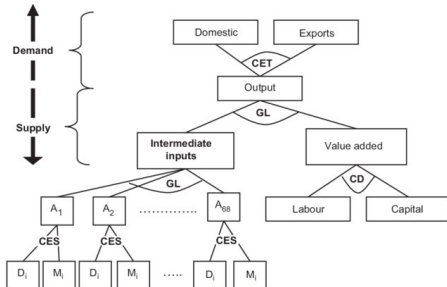
CES (2)



Source: Rybalka et al. (2018), https://www.researchgate.net/publication/328335194_Evaluation_of_the_regionally_differentiated_social_security_contributions_in_Norway

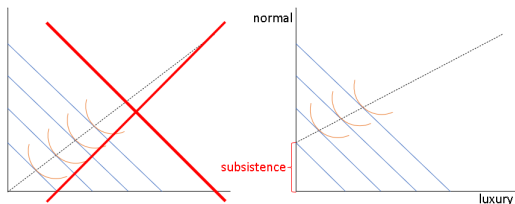
Special cases of CES

- $\sigma = 0$: Leontief (components in constant proportions)
 - in GTAP e.g. commodities into industry-specific intermediate use
- $\sigma = 1$: Cobb-Douglas (1:1 replacement)
 - in GTAP e.g. commodities into final investment / government demand



Household consumption aggregate

- More complicated due to Engel's law.
- GTAP uses **Constant Difference in Elasticities (CDE)** aggregator.
 - Technical exposition: <https://www.gtap.agecon.purdue.edu/resources/download/291.pdf>
 - Parameter matrices $C \times C$ (substitution) and $C \times 1$ (income).
- Similar logic, but analytically more transparent: **Linear Expenditure System (LES)**.



Quantities, prices, values

- Data expressed in VALUES ($V = Q \times P$)
- Model formulated in VOLUMES (Q) AND PRICES (P)

Assumptions

- All prices in baseline equilibrium = 1.
- One of them (*numeraire*) also = 1 in the newly simulated equilibrium.
- Also some broad average can be appointed as *numeraire* (as GTAP does).

This allows to simulate % changes in Q and P without much loss of generality.

Walras law

The sum of the values of **excess demands** across all markets must **equal zero**, whether or not the economy is in a general equilibrium.

Implication: if all markets but one in equilibrium ($D=S$), the last one in equilibrium as well.

CGE models have options of introducing excess demand or supply in some markets using *slack* variables.

- the standard choice is setting all slacks = 0 (as exogenous variables)
- when a slack variable $\neq 0$, there is no equilibrium in some market
- one special slack variable in GTAP related to the *last* market: **walraslack** (endogenous, = 0 in general equilibrium)

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Linearization

Model equations: linear or (usually) non-linear. The latter can be represented as linear with: (i) non-constant coefficients, (ii) re-defined variables, and then solved at a reasonable accuracy.

Action	General rule	Example
equation	$F(Y, L) = 0$	$Y = \alpha_0 L^{\alpha_1}$ $Y - \alpha_0 L^{\alpha_1} = 0$
differential	$\frac{\partial F}{\partial Y}(Y, L)\Delta Y + \frac{\partial F}{\partial L}(Y, L)\Delta L = 0$	$\Delta Y -$ $\alpha_0 \alpha_1 L^{\alpha_1 - 1} \Delta L = 0$
percentage deviations...	$Y \underbrace{\frac{\partial F}{\partial Y}(Y, L) \frac{\Delta Y}{Y} \cdot 100\%}_y + L \underbrace{\frac{\partial F}{\partial L}(Y, L) \frac{\Delta L}{L} \cdot 100\%}_l = 0$	$Y y - \alpha_0 \alpha_1 L^{\alpha_1} l = 0$
...level-dep. coefficients	$Y \frac{\partial F}{\partial Y}(Y, L) y + L \frac{\partial F}{\partial L}(Y, L) l = 0$	

- for y , **given** l (y endogenous, l exogenous)
- for l , **given** y (l endogenous, y exogenous)

The diagram shows a large square matrix of size $K \times K$ on the left, labeled "coefficients" and "endo". This matrix is added to a smaller square matrix of size $K \times (N-K)$ on the right, labeled "coefficients" and "exo". The result is an equals sign followed by a zero, indicating that the sum of these two matrices equals zero.

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Closure

MODEL DESCRIPTION



MODEL ASSUMPTIONS



ELASTICITIES



made with neuronic

CLOSURE



Source: *Mateusz, an experienced CGE user from consulting industry.*

Solution: example (R code)

Imagine using our Mickey-Mouse model

$$Y = \alpha_0 L^{\alpha_1}$$

with:

- baseline equilibrium $L_0 = 50, Y_0 = 100$
- elasticity $\alpha_1 = 0.7$
- α_0 as implied by baseline equilibrium and elasticity

The model is cast into the form:

$$A(Y, L) \cdot y + B(Y, L) \cdot l = 0$$

Closure: L exogenous.

Consider L increasing from 50 to 55. Solve the model.

```
L_0 <- 50
Y_0 <- 100

#Set elasticities (external calibration)
alpha_1 <- 0.7
#Set other parameters (level calibration)
alpha_0 <- Y_0 / (L_0 ^ alpha_1)

#Parameter matrices of linearized model:
A <- function(Y) {
  return(Y)
}
B <- function(L, alpha_0, alpha_1) {
  return( -alpha_0 * alpha_1 * (L^alpha_1) )
}
#Equation(s) of linearized model
solution <- function(l, A, B) {
  - B / A * l
}

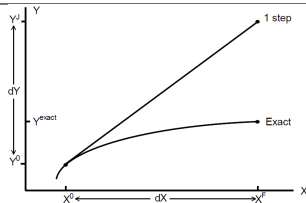
#In "baseline equilibrium"
A_0 <- A(Y_0)
B_0 <- B(L_0, alpha_0, alpha_1)

#Simulation scenario
L_1 <- 55
l <- ((L_1-L_0) / L_0)*100
```

Solution: Johansen vs Euler (R code)

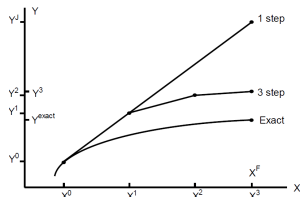
Johansen

```
#Solution: Johansen method
y <- solution(l, A_0, B_0)
Y_Johansen <- (1 + y / 100) * Y_0
```



Euler

```
#Solution: Euler method
n_steps <- 5
L_step <- (L_1 - L_0) / n_steps
Y_s <- Y_0
L_s <- L_0
for (s in 1:n_steps) {
  A_s <- A(Y_s)
  B_s <- B(L_s, alpha_0, alpha_1)
  L_s <- L_s + L_step
  l_step <- (L_step / L_s) * 100
  y_s <- solution(l_step, A_s, B_s)
  Y_s <- (1 + y_s / 100) * Y_s
}
Y_Euler5 <- Y_s
```



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Setting up RunGTAP

- Install RunGTAP.
- Version > Change > UNCON3X3
 - This changes GTAP6.2 model to its *uncondensed* version. This means that we can access and shock more variables (otherwise skipped for numerical efficiency).
- Version > New > Next > New Aggregation [Give name] & Next > Locate ZIP archive [at the bottom & use the supplied ZIP file & rest unchanged] & Next > FINISH
 - This provides data at a given sectorial and regional aggregation. Some training datasets are provided (Version > Change), e.g. for Burfisher's handbook.

Tax variables in GTAP

- “naturally” exogenous in standard closures
- naming convention: t^* , e.g. indirect tax on household consumption of domestic goods: **tpd**
- CGEs extensively use the **power of the tax** notion:

$$\frac{\text{tax base plus tax value}}{\text{tax base}}$$

normally > 1 (when net taxes > 0 , i.e. taxes $>$ subsidies)

- tx = shock to (i.e. % change in) the power of the tax x

Tax variable shock (1)

Consider a policy of lower VAT for food in DE: 19% → 16%. GTAP data implies a higher effective indirect tax rate on top of producer's price, so let us lower that rate by $\frac{16\%-19\%}{19\%} \cdot 100\% = -15.7895\%$, for both domestic and imported goods.

Example: indirect tax, *ProcFood*, *Germany*

baseline (initial), *ad valorem* rate: 33.0811%

% change *ad valorem* rate: $\frac{16\%-19\%}{19\%} \cdot 100\% = -15.7895\%$

target (final), *ad valorem* rate: 27.8577%

baseline (initial) power of the tax: $\frac{100+33.0811}{100} = 1.330811$

target (final) power of the tax: $\frac{100+27.8577}{100} = 1.278577$

% change power of the tax: $\frac{1.278577-1.330811}{1.330811} \cdot 100\% = -3.9249\%$

Shock `tpd("ProcFood","Germany") = -3.9249;`

Tax variable shock (2)

After shocking **tpd**, do the same to **tpm** to get:

Title	RunGTAP	Version	Closure	Shocks	Solve
Variable to Shock	<input type="text" value="tpm"/>	comm.-, source-spec. shift in tax on private cons. of imp. Dimensions: TRAD_COMM*REG			
Elements to Shock	<input type="text" value="ProcFood"/>	<input type="text" value="Germany"/>			
Shock Value	<input type="text" value="-15.7895"/>	Type of Shock	<input type="text" value="%change rate"/>		
file tpm.shk: -24.2858	initial AV% rate: 32.0757	final AV% rate: 27.0111	%power shock: -3.8346		
Shock tpm("ProcFood","Germany") = -3.8346;					
Add to Shock List		Clear Shocks List		Define Subtotal	
Use period not comma as decimal separator if you type into the box below.					
Shock tpd("ProcFood","Germany") = -3.9249; Shock tpm("ProcFood","Germany") = -3.8346;					

CGE story for Exercise 1

- ❶ PM – market prices (% changes) – almost 0 for ProcFood, only contain taxes on producers
- ❷ View > TAB Files > Main Model > Ctrl+F: “tpd” (shocked variable), see l. 1081, 1087, 1092 > PPD, PPM are consumer prices
- ❸ PPD on ProcFood – reduced
- ❹ QO (output quantity) – up for ProcFood, up or down on other categories (consumer substitution)
- ❺ QXS (trade flow quantities) – 3D result, so we have to choose a “slice” to see a table, pick “ProcFood”
 - ❶ imports to DE increase (PPM went down as well as PPD!)
 - ❷ flows from DE to DE increased! what should that mean? For multi-country regions, this means trade between region members. For Germany, just change 1 (Sim) (percentage changes) to 2 Pre or 3 Post (pre- or post simulation levels) and re-open the view...
- ❻ Aggregate assessment: qgdp (change in real GDP) and EV (= Equivalent Variation = change in consumption with the same impact on welfare)

CGE story for Exercise 1

ppd	NAmerica	EuropeExDE	Germany	RusBel	ROW
Agriculture	0,01	0,04	0,17	0,01	0,01
OilGasCoal	-0,00	-0,00	0,00	-0,00	-0,00
ProcFood	0,00	0,01	-3,91	0,00	0,00
Manufact	-0,00	0,00	-0,02	-0,00	-0,00
EnergyIntens	-0,00	0,00	-0,02	-0,00	-0,00
Construction	-0,00	0,00	-0,02	-0,00	-0,00
Transport	-0,00	0,00	-0,02	-0,00	-0,00
OthServices	-0,00	0,00	-0,03	-0,00	-0,00

CGE story for Exercise 1

qo	NAmerica	EuropeExDE	Germany	RusBel	ROW
Agriculture	0,01	0,07	0,48	0,01	0,01
OilGasCoal	-0,00	-0,00	0,03	-0,00	-0,00
ProcFood	0,00	0,09	1,48	0,01	0,01
Manufact	-0,00	-0,02	0,07	-0,00	-0,00
EnergyIntens	-0,00	-0,01	0,05	-0,00	-0,00
Construction	-0,00	0,00	-0,07	-0,00	-0,00
Transport	0,00	-0,00	-0,01	0,00	-0,00
OthServices	0,00	-0,00	-0,07	-0,00	-0,00
CGDS	-0,00	0,00	-0,10	-0,00	-0,00

CGE story for Exercise 1

ProcFood	2	Contents	Description	1 (Sim)	
qxs[ProcFood**]	NAmerica	EuropeExDE	Germany	RusBel	ROW
NAmerica	0,01	0,06	1,93	0,01	0,01
EuropeExDE	-0,04	0,02	1,89	-0,03	-0,03
Germany	-0,04	0,01	1,88	-0,03	-0,03
RusBel	0,01	0,06	1,93	0,01	0,01
ROW	-0,00	0,05	1,92	0,00	0,00

ProcFood	2	Contents	Description	2 Pre	
qxs[ProcFood**]	NAmerica	EuropeExDE	Germany	RusBel	ROW
NAmerica	57555,33	8696,23	1840,61	1126,16	51325,85
EuropeExDE	25623,35	210672,19	52198,53	8991,47	76520,31
Germany	1976,66	59032,41	0,00	1478,60	9768,11
RusBel	439,57	2433,45	267,67	4372,30	8340,59
ROW	50650,72	59536,41	11404,81	10804,33	285184,59

CGE story for Exercise 1

qgdp	(Sim)
NAmerica	-0,00
EuropeExDE	-0,00
Germany	0,02
RusBel	-0,00
ROW	-0,00

EV	(Sim)
NAmerica	4,94
EuropeExDE	225,33
Germany	679,69
RusBel	-10,86
ROW	-55,80

Changing closure (1)

Consider a policy of a ban on importing oil, gas & coal from Russia in all Western regions: DE, EU ex. DE and North America.

- Trade volume variable: **qxs**(com,ro,rd)
 - com: commodity
 - ro: region of origin
 - rd: region of destination
- This variable is endogenous – cannot be just changed. We have to declare it as exogenous, which requires replacing it with another variable of the same size in the set of endogenous (and let it adjust accordingly).
- Changing closure – most difficult part, involving deep understanding of the model and underlying economic theory. For sanctions, two popular swap variables to trade quantity qxs:
 - ① **tms**(com, ro, rd) – to reduce trade flow by a given %, increase **tariff** by a necessary %
 - ② **ams**(com, ro, rd) - to reduce trade flow by a given %, deteriorate **transport technology** by a necessary % to make the shipment melt like an **iceberg**

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Changing closure (2)

One can either edit the list of exogenous variables directly, or – more conveniently and transparently – use the standard list supplemented with *swap* statements.

RunGTAP: denru/OilRusEu Sanctions on Russian energy fuels

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Title	RunGTAP	Version	Closure	Shocks	Solve
<pre> exogenous pop psaveslack pfactwld profitslack incomeslack endwslack cgdslack tradslack ams atm atf ats atd aosec aoreg avasec avareg afcom afsec afreg afecom afesec afereg aoall afall afeall au dppriv dpgov dpsave to tp tm tms tx txs qo(ENDW_COMM,REG) atall avaall tf tfd tfm tgd tpd tgm tpm; Rest Endogenous; swap qxs("OilGasCoal","RusBel","Germany") = ams("OilGasCoal","RusBel","Germany"); swap qxs("OilGasCoal","RusBel","EuropeExDE") = ams("OilGasCoal","RusBel","EuropeExDE"); swap qxs("OilGasCoal","RusBel","NAmerica") = ams("OilGasCoal","RusBel","NAmerica"); </pre>					

Shocks to trade flow quantities (qxs)

RunGTAP: denru/OilRusEu Sanctions on Russian energy fuels

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Title	RunGTAP	Version	Closure	Shocks	Solve
Variable to Shock	qxs	export sales of commodity i from r to region s Dimensions: TRAD_COMM*REG*REG			
Elements to Shock	OilGasCoal	RusBel	NAmerica		
% Change Shock	-100				

```
Shock gxs("OilGasCoal","RusBel","NAmerica") = -100;
```

Add to Shock List

Clear Shocks List

Define Subtotal

Use period not comma as decimal separator if you type into the box below.

```
Shock qxs("OilGasCoal","RusBel","NAmerica") = -100;
Shock qxs("OilGasCoal","RusBel","EuropeExDE") = -100;
Shock qxs("OilGasCoal","RusBel","Germany") = -100;
```

CGE story for Ex. 2

qxs[OilGasCoal**]	NAmerica	EuropeExDE	Germany	RusBel	ROW
NAmerica	0,94	49,88	70,44	-50,65	-4,52
EuropeExDE	-26,72	9,66	24,84	-62,76	-31,26
Germany	-24,69	8,72	14,90	-63,73	-29,77
RusBel	-100,00	-100,00	-100,00	13,33	115,71
ROW	0,14	49,15	68,74	-50,22	-5,39

CGE story for Ex. 2

pm	NAmerica	EuropeExDE	Germany	RusBel	ROW
Agriculture	0,05	-0,15	-0,22	-0,69	0,02
OilGasCoal	2,09	4,75	5,04	-4,48	2,10
ProcFood	0,09	-0,18	-0,16	-0,95	0,07
Manufact	0,16	-0,05	-0,08	-1,37	0,24
EnergyIntens	0,64	0,93	0,90	-2,80	0,65
Construction	0,13	-0,18	-0,20	-1,06	0,22
Transport	0,10	-0,21	-0,24	-1,18	0,11
OthServices	0,05	-0,35	-0,37	-1,10	0,07

CGE story for Ex. 2

qo	NAmerica	EuropeExDE	Germany	RusBel	ROW
Agriculture	-0,10	0,09	0,19	0,14	-0,05
OilGasCoal	1,09	3,20	4,29	-1,98	1,23
ProcFood	-0,05	0,03	-0,10	-0,61	-0,04
Manufact	-0,06	0,43	0,64	2,97	-0,39
EnergyIntens	-0,24	-1,33	-1,16	7,73	-0,28
Construction	0,04	-0,29	-0,45	0,19	-0,01
Transport	-0,03	-0,03	-0,03	-0,50	-0,06
OthServices	-0,00	0,02	-0,04	-1,28	0,02

CGE story for Ex. 2

		EV	(Sim)
qgdp	(Sim)	NAmerica	-351,16
NAmerica	0,00	EuropeExDE	-26277,18
EuropeExDE	-0,16	Germany	-9622,75
Germany	-0,18	RusBel	-38927,16
RusBel	-1,08	ROW	20433,40
ROW	0,00		

EV(REG) [change]: equivalent variation, \$ US million

Conclusion

Simulating a scenario in CGE:

- starts with setting a selected (exogenous) variable at a given level (tax hike, technology shift, etc.), usually at a sectorial resolution;
- accounts for all agents' responses in the economy (GE);
- takes some computational effort to solve the model (and hence special software);
- requires a critical review of elasticities and closure.

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Try this at home!

What if

(a) the same indirect tax decrease (on *ProcFood*) is harmonized across EU?

(b) Western trade sanctions on Russia are extended to *ProcFood*, and both ways (export and import)?

Thank You!

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