Circular economy innovations in a 2-area input-output stock-flow consistent dynamic model

Marco Veronese Passarella
(University of Leeds)

– with A. Genovese (University of Sheffield), J.B.R.T. Fevereiro (University of Sheffield), and O.V. Codina (University of Leeds) –

European Commission Grant, Project 101003491: "A Just Transition to the Circular Economy" (JUST2CE)

October 2023

Download this presentation from:

https://www.marcopassarella.it/en/circular-economy-innovations-4/

Introduction: what is just2ce?

- **JUST2CE** = A Just Transition to the Circular Economy

Introduction: what is just2ce?

- **JUST2CE** = A Just Transition to the Circular Economy
- It is a EU-funded project proposing an alternative way to looking at CE

Introduction: what is just2ce?

- **JUST2CE** = A Just Transition to the Circular Economy
- It is a EU-funded project proposing an alternative way to looking at CE
- Most projects have focused on how to produce circularity. JUST2CE focuses on what (democracy, participation, gender, global justice)

Introduction: what is just2ce?

- **JUST2CE** = A Just Transition to the Circular Economy
- It is a EU-funded project proposing an alternative way to looking at CE
- Most projects have focused on how to produce circularity. JUST2CE focuses on what (democracy, participation, gender, global justice)
- Two main milestones / deliverables linked with WP5:

Introduction: what is just2ce?

- **JUST2CE** = A Just Transition to the Circular Economy
- It is a EU-funded project proposing an alternative way to looking at CE
- Most projects have focused on how to produce circularity. JUST2CE focuses on what (democracy, participation, gender, global justice)
- Two main milestones / deliverables linked with WP5:
  - a systematic review of current literature on macroeconomic models for assessing the transition towards a CE

Introduction: what is just2ce?

- **JUST2CE** = A Just Transition to the Circular Economy
- It is a EU-funded project proposing an alternative way to looking at CE
- Most projects have focused on how to produce circularity. JUST2CE focuses on what (democracy, participation, gender, global justice)
- Two main milestones / deliverables linked with WP5:
  - a systematic review of current literature on macroeconomic models for assessing the transition towards a CE
  - a formal model (or set of models) to simulate and compare alternative CE policies and transition scenarios

A systematic literature review

– We have analyzed 49,893 papers (see Valles-Codina et al. 2022)

A systematic literature review

- We have analyzed 49,893 papers (see Valles-Codina et al. 2022)
- Eventually, 55 have been selected

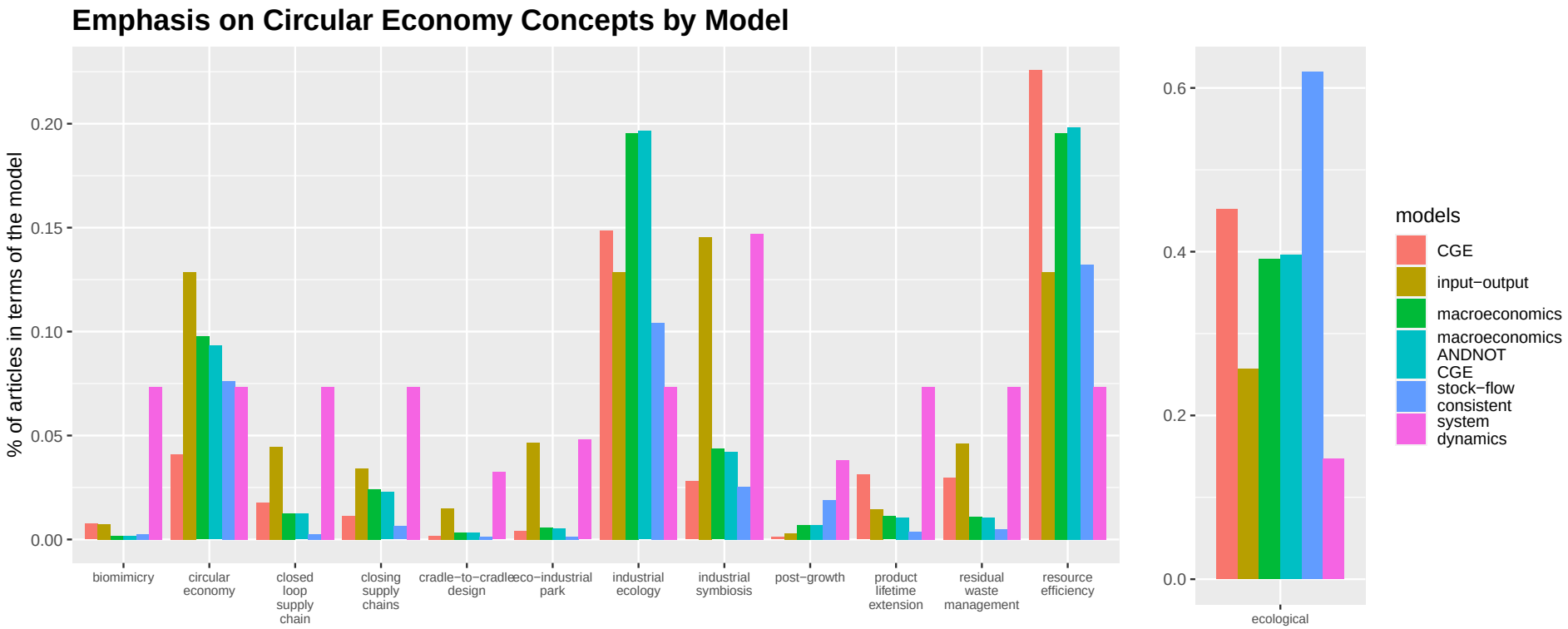
A systematic literature review

- We have analyzed 49,893 papers (see Valles-Codina et al. 2022)
- Eventually, 55 have been selected
- We have focused on both topics and modeling techniques

A systematic literature review

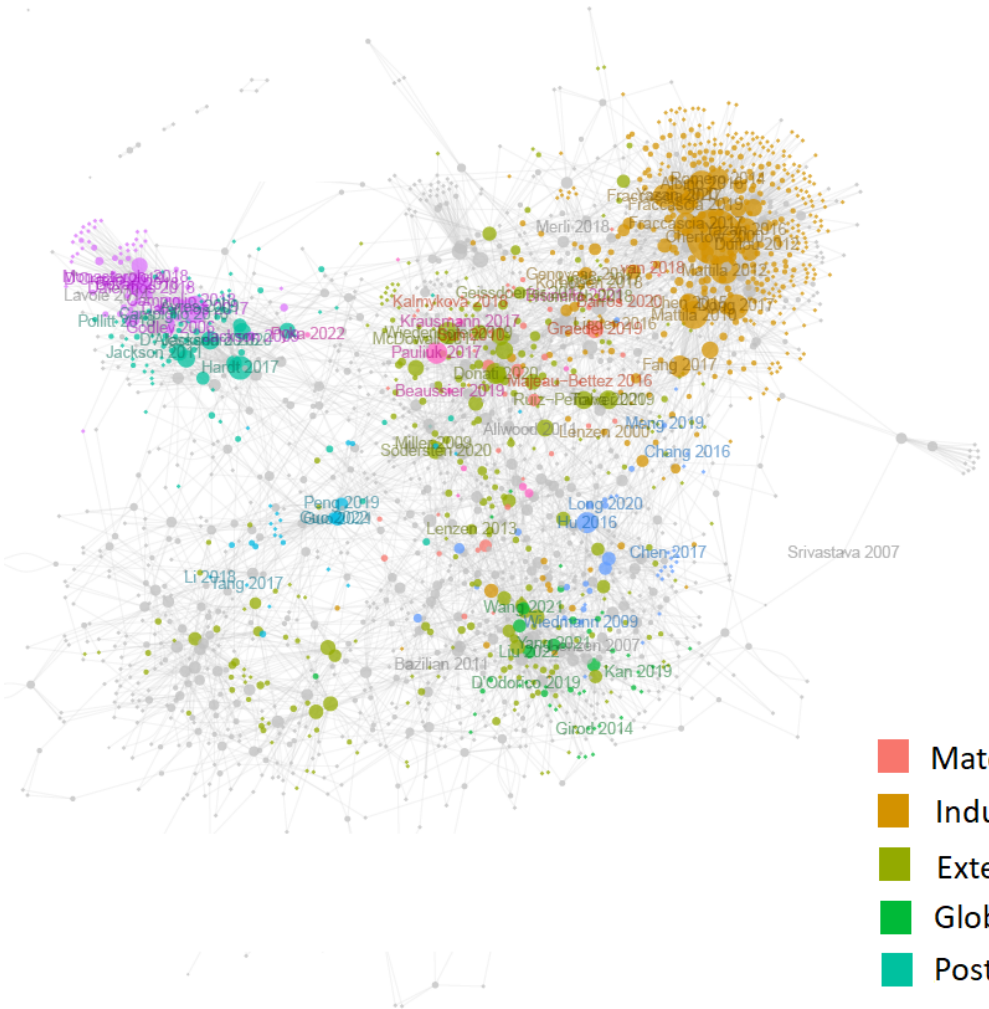
- We have analyzed 49,893 papers (see Valles-Codina et al. 2022)
- Eventually, 55 have been selected
- We have focused on both topics and modeling techniques
- We have identified, discussed, and assessed the most popular/promising tools (to model the transition...)

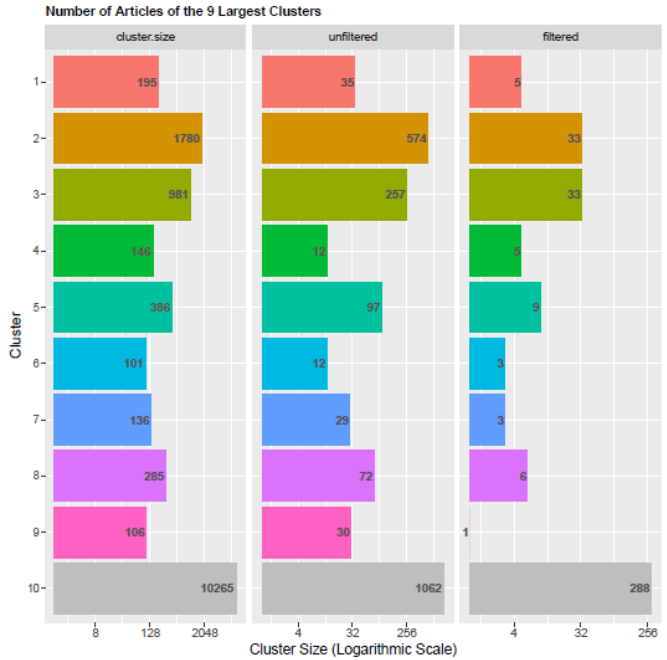
Figure A1. Concepts and models



Source: Valles-Codina et al. (2022)

Figure A2. Citation network of filtered entries





- Material flow analysis
- Industrial symbiosis
- Extended IO
- Global value chain
- Post-growth SFC
- CGE (electric vehicles)
- Carbon footprint analysis
- Post-Keynesian SFC
- IAMs

Source: elaboration on Valles-Codina et al. (2022)

The model: basic features

– Main tools in (theory-to-data) macroeconomics:

The model: basic features

- Main tools in (theory-to-data) macroeconomics:
  1) DSGE (and growth) models. Pros: mainstream tool, simple story. Cons: too "small", unique optimal equilibrium

The model: basic features

- Main tools in (theory-to-data) macroeconomics:
  1) DSGE (and growth) models. Pros: mainstream tool, simple story. Cons: too "small", unique optimal equilibrium
  2) CGE models (and IAMs). Pros: several variables, cross-industry interdependencies. Cons: unique optimal equilibrium

The model: basic features

- Main tools in (theory-to-data) macroeconomics:
  1) DSGE (and growth) models. Pros: mainstream tool, simple story. Cons: too "small", unique optimal equilibrium
  2) CGE models (and IAMs). Pros: several variables, cross-industry interdependencies. Cons: unique optimal equilibrium
- Is there an alternative? Yes, there are two:

The model: basic features

- Main tools in (theory-to-data) macroeconomics:
  1) DSGE (and growth) models. Pros: mainstream tool, simple story. Cons: too "small", unique optimal equilibrium
  2) CGE models (and IAMs). Pros: several variables, cross-industry interdependencies. Cons: unique optimal equilibrium
- Is there an alternative? Yes, there are two:
  1) Leontief IO models. Pros: several variables, cross-industry interdependencies. Cons: static, poor financial side

The model: basic features

- Main tools in (theory-to-data) macroeconomics:
  1) DSGE (and growth) models. Pros: mainstream tool, simple story. Cons: too "small", unique optimal equilibrium
  2) CGE models (and IAMs). Pros: several variables, cross-industry interdependencies. Cons: unique optimal equilibrium
- Is there an alternative? Yes, there are two:
  1) Leontief IO models. Pros: several variables, cross-industry interdependencies. Cons: static, poor financial side
  2) SFC models. Pros: dynamics, finance. Cons: homogeneous output

The model: basic features

- Main tools in (theory-to-data) macroeconomics:
  1) DSGE (and growth) models. Pros: mainstream tool, simple story. Cons: too "small", unique optimal equilibrium
  2) CGE models (and IAMs). Pros: several variables, cross-industry interdependencies. Cons: unique optimal equilibrium
- Is there an alternative? Yes, there are two:
  1) Leontief IO models. Pros: several variables, cross-industry interdependencies. Cons: static, poor financial side
  2) SFC models. Pros: dynamics, finance. Cons: homogeneous output
- In principle, we can disaggregate SFC models by crossbreeding them with IO models... (Hardt and O'Neill 2017)

Aim / Research questions

– However, just a few papers use IO-SFC models:

Aim / Research questions

- However, just a few papers use IO-SFC models:
  - Berg, Hartley and Richters (2015). A stock-flow consistent input-output model with applications to energy price shocks, interest rates, and heat emissions. *New Journal of Physics*.

Aim / Research questions

- However, just a few papers use IO-SFC models:
  - Berg, Hartley and Richters (2015). A stock-flow consistent input-output model with applications to energy price shocks, interest rates, and heat emissions. *New Journal of Physics*.
  - Other contributions: Naqvi (2015), Valdecantos and Valentini (2017), Jackson and Jackson (2021, 2023), Cordier et al. (2015), Jackson et al. (2014), Di Domenico and Di Domenico (2023), Valdecantos (2023), Pettena and Raberto (2023), Zezza and Zezza (2023)

Aim / Research questions

- However, just a few papers use IO-SFC models:
  - Berg, Hartley and Richters (2015). A stock-flow consistent input-output model with applications to energy price shocks, interest rates, and heat emissions. *New Journal of Physics*.
  - Other contributions: Naqvi (2015), Valdecantos and Valentini (2017), Jackson and Jackson (2021, 2023), Cordier et al. (2015), Jackson et al. (2014), Di Domenico and Di Domenico (2023), Valdecantos (2023), Pettena and Raberto (2023), Zezza and Zezza (2023)
- No focus on (transition towards) CE, no cross-area effects

Aim / Research questions

- However, just a few papers use IO-SFC models:
  - Berg, Hartley and Richters (2015). A stock-flow consistent input-output model with applications to energy price shocks, interest rates, and heat emissions. *New Journal of Physics*.
  - Other contributions: Naqvi (2015), Valdecantos and Valentini (2017), Jackson and Jackson (2021, 2023), Cordier et al. (2015), Jackson et al. (2014), Di Domenico and Di Domenico (2023), Valdecantos (2023), Pettena and Raberto (2023), Zezza and Zezza (2023)
- No focus on (transition towards) CE, no cross-area effects
- Two-fold aim:

Aim / Research questions

- However, just a few papers use IO-SFC models:
  - Berg, Hartley and Richters (2015). A stock-flow consistent input-output model with applications to energy price shocks, interest rates, and heat emissions. *New Journal of Physics*.
  - Other contributions: Naqvi (2015), Valdecantos and Valentini (2017), Jackson and Jackson (2021, 2023), Cordier et al. (2015), Jackson et al. (2014), Di Domenico and Di Domenico (2023), Valdecantos (2023), Pettena and Raberto (2023), Zezza and Zezza (2023)
- No focus on (transition towards) CE, no cross-area effects
- Two-fold aim:
  1) To bridge the gap by developing a benchmark 2A-IO-SFC model (and related codes)

Aim / Research questions

- However, just a few papers use IO-SFC models:
  - Berg, Hartley and Richters (2015). A stock-flow consistent input-output model with applications to energy price shocks, interest rates, and heat emissions. *New Journal of Physics*.
  - Other contributions: Naqvi (2015), Valdecantos and Valentini (2017), Jackson and Jackson (2021, 2023), Cordier et al. (2015), Jackson et al. (2014), Di Domenico and Di Domenico (2023), Valdecantos (2023), Pettena and Raberto (2023), Zezza and Zezza (2023)
- No focus on (transition towards) CE, no cross-area effects
- Two-fold aim:
  1) To bridge the gap by developing a benchmark 2A-IO-SFC model (and related codes)
  2) To assess the impact of a simple CE innovation on the economy, the society and the ecosystem

Method

a) Macro frame taken from standard SFC models (Godley and Lavoie 2007):

Method

a) Macro frame taken from standard SFC models (Godley and Lavoie 2007):

- Five domestic sectors: households, production firms, government, commercial banks, central bank

Method

a) Macro frame taken from standard SFC models (Godley and Lavoie 2007):

- Five domestic sectors: households, production firms, government, commercial banks, central bank
- Six assets: cash, bank deposits, domestic T-bills, foreign T-bills, domestic shares, foreign shares (+ advances from CB)

Method

a) Macro frame taken from standard SFC models (Godley and Lavoie 2007):

- Five domestic sectors: households, production firms, government, commercial banks, central bank
- Six assets: cash, bank deposits, domestic T-bills, foreign T-bills, domestic shares, foreign shares (+ advances from CB)
- Both loans to firms and personal loans

Method

a) Macro frame taken from standard SFC models (Godley and Lavoie 2007):

- Five domestic sectors: households, production firms, government, commercial banks, central bank
- Six assets: cash, bank deposits, domestic T-bills, foreign T-bills, domestic shares, foreign shares (+ advances from CB)
- Both loans to firms and personal loans
- Fixed capital and durable goods, but no inventories

Method

a) Macro frame taken from standard SFC models (Godley and Lavoie 2007):
   - Five domestic sectors: households, production firms, government, commercial banks, central bank
   - Six assets: cash, bank deposits, domestic T-bills, foreign T-bills, domestic shares, foreign shares (+ advances from CB)
   - Both loans to firms and personal loans
   - Fixed capital and durable goods, but no inventories

b) Simple IO structure – 4+1 industries: manufacturing, agriculture, services, waste management, recycling

Method

a) Macro frame taken from standard SFC models (Godley and Lavoie 2007):
   - Five domestic sectors: households, production firms, government, commercial banks, central bank
   - Six assets: cash, bank deposits, domestic T-bills, foreign T-bills, domestic shares, foreign shares (+ advances from CB)
   - Both loans to firms and personal loans
   - Fixed capital and durable goods, but no inventories

b) Simple IO structure – 4+1 industries: manufacturing, agriculture, services, waste management, recycling

c) Identification: *Exiobase* (EU vs RoW) / literature / reasonable values

Method

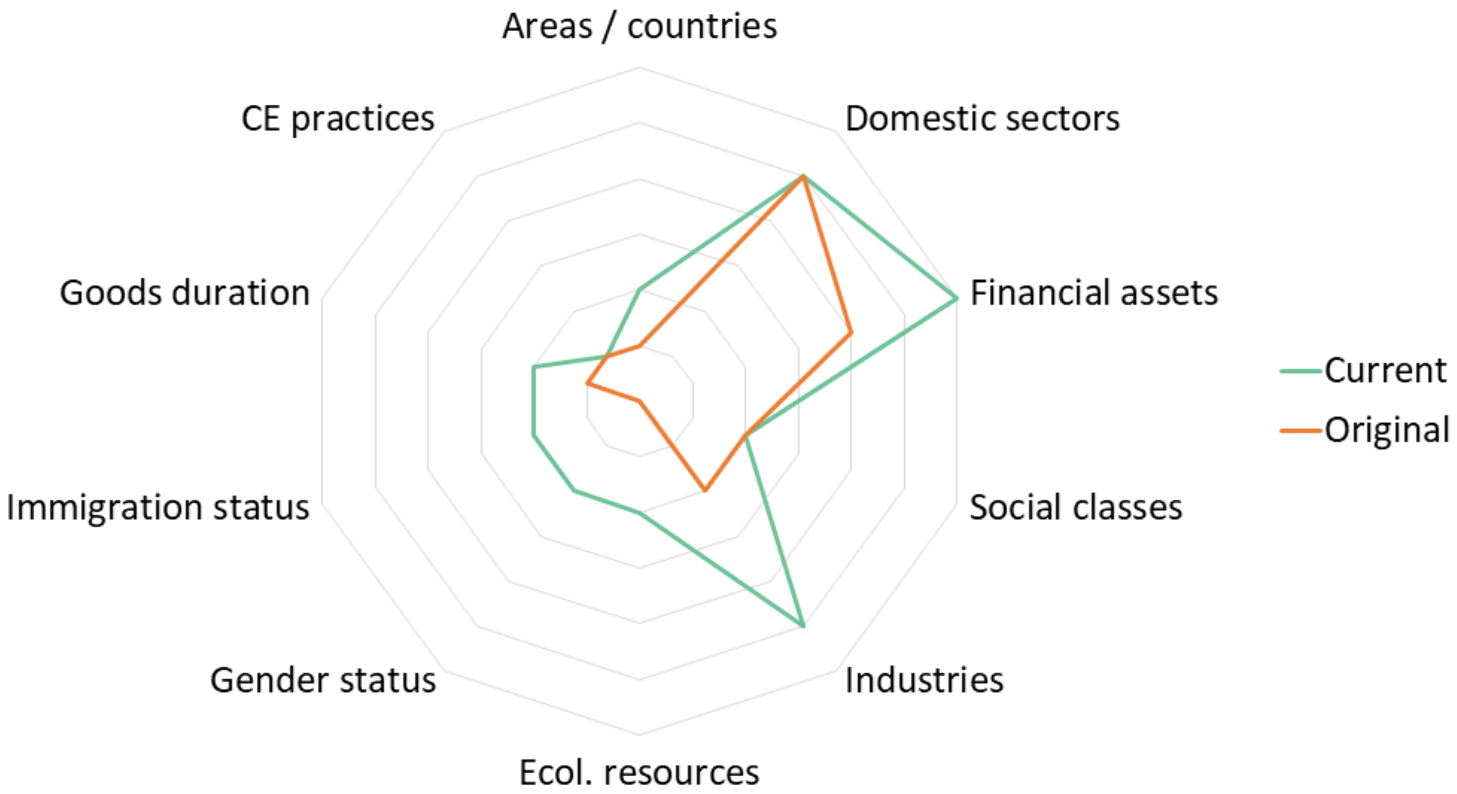
a) Macro frame taken from standard SFC models (Godley and Lavoie 2007):
   - Five domestic sectors: households, production firms, government, commercial banks, central bank
   - Six assets: cash, bank deposits, domestic T-bills, foreign T-bills, domestic shares, foreign shares (+ advances from CB)
   - Both loans to firms and personal loans
   - Fixed capital and durable goods, but no inventories

b) Simple IO structure – 4+1 industries: manufacturing, agriculture, services, waste management, recycling

c) Identification: *Exiobase* (EU vs RoW) / literature / reasonable values

d) Solution: numerical simulations (*R* code), 100 periods, 100 iterations

Figure 1. Model dimensions



Assets and liabilities

Table 1: Balance-sheet matrix in period 20 (curr. p., EU currency)

	EU						RoW					
	H	F	G	B	CB	*xr*	H	F	G	B	CB	Tot
Money	62.21				-62.21	1	83.47				-83.47	0.00
Advances						1						0.00
Deposits	372.61			-372.61		1	499.46			-499.46		0.00
Loans	-13.33	-85.00		98.33		1	-17.03	-111.45		128.48		0.00
EU bills	23.31		-926.45	274.27	613.21	1	15.65					0.00
RoW bills	11.66				-551.01	1	31.30		53.61	370.98	83.47	0.00
EU shares	9.32	-9.95				1	0.63					0.00
RoW shares	0.47					1	12.52	-12.99				0.00
Capital stock		94.95				1		124.44				219.39
Net financial wealth	-466.24		926.45			1	-625.99		-53.61			-219.39
Total	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00

Transactions and Δ in stocks

Table 2: Transactions-flow matrix in period 20 (curr. p., EU currency)

	EU							RoW						
	H	F (y)	F (k)	G	B	CB	*xr*	H	F (y)	F (k)	G	B	CB	Tot
Consumption	-621.39	621.39					1	-837.43	837.43					0.00
Investment		6.65	-6.65				1		9.28	-9.28				0.00
Government spending		180.8		-180.80			1		181.09		-181.09			0.00
Export of EU		86.84					1		-86.84					0.00
Import of EU		-112.01					1		112.01					0.00
[Value added]		[769.61]					1		[1034.5]					
Wage bill	455.42	-455.42					1	568.70	-568.7					0.00
Corporate profit	303.47	-306.22					1	458.15	-455.4					0.00
Amortization		-4.65	4.65				1		-6.06	6.06				0.00
Bank profit	7.44				-7.44		1	9.93				-9.93		0.00
CB profit				2.49		-2.49	1				3.32		-3.32	0.00
Income tax revenue	-153.55			153.55			1	-207.73			207.73			0.00
VAT revenue		-6.15		6.15			1		-8.29		8.29			0.00
Tariffs revenue		-7.89		10.18			1		-10.18		7.89			0.00
Interests on deposits	7.44				-7.44		1	9.93				-9.93		0.00
Interests on loans	-0.50	-3.32			3.82		1	-0.64	-4.33			4.97		0.00
Interests on EU bills	0.93			-35.31	11.06	22.69	1	0.62						0.00
Interests on RoW bills	0.47					-20.20	1	1.25			0.29	14.88	3.32	0.00
Change in money stock	0.04					-0.04	1	-0.38					0.38	0.00
Change in advances							1							0.00
Change in deposits	-0.53				0.53		1	-3.13				3.13		0.00
Change in loans	0.73		2.00		-2.73		1			3.16		-4.16		0.00
Change in EU bills	0.01			43.73	2.20	-45.88	1	-0.07						0.00
Change in RoW bills	0.01					45.91	1	-0.14			-46.43	1.03	-0.38	0.00
Change in EU shares	0.01						1							0.00
Change in RoW shares							1	-0.06		0.06				0.00
Revaluation effects							1							0.00
Total	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cross-industry interdependencies

Table 3: Baseline: IO matrix in period 20 (curr. p., EU currency, no calibration)

	EU demand for inputs					RoW demand for inputs						
	M	A	S	W	R	M	A	S	W	R	Final dem.	Output
EU production												
Manufacturing	67.01	66.89	67.13	26.13	0.00	5.58	5.57	5.59	2.18	0.00	312.33	558.43
Agriculture	67.01	66.89	67.13	26.13	0.00	5.58	5.57	5.59	2.18	0.00	311.35	557.45
Services	67.01	66.89	67.13	26.13	0.00	5.58	5.57	5.59	2.18	0.00	313.31	559.41
Waste manag.	67.00	66.89	67.12	0.00	0.00	5.58	5.57	5.59	0.00	0.00	0.00	217.76
Recycling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RoW production												
Manufacturing	5.58	5.57	5.59	2.18	0.00	67.01	66.89	67.13	26.13	0.00	312.33	558.43
Agriculture	5.58	5.57	5.59	2.18	0.00	67.01	66.89	67.13	26.13	0.00	311.35	557.45
Services	5.58	5.57	5.59	2.18	0.00	67.01	66.89	67.13	26.13	0.00	313.31	559.41
Waste manag.	5.58	5.57	5.59	0.00	0.00	67.00	66.89	67.12	0.00	0.00	0.00	217.76
Recycling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Value added												
~ Compensation of employees	128.65	128.41	128.89	46.55	0.00	128.65	128.41	128.89	46.55	0.00		
~ G.O. surplus and mixed incomes	139.41	139.18	139.64	86.27	0.00	139.41	139.18	139.64	86.27	0.00		
Taxes on production	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Output	558.43	557.45	559.41	217.76	0.00	558.43	557.45	559.41	217.76	0.00		

Area-specific physical flows

Table 4: Physical flow matrix in period 20 (matter = Gt, energy = EJ)

	EU matter	RoW matter	Global matter	EU energy	RoW energy	Global energy
Inputs						
Extracted matter	317.86	2141.84	2459.7			
Recycled matter	7.72	55.3	63.03			
Renewable energy			0	1176.34	1461.97	2638.31
Non-renewable energy	17.37	23.33	40.7	7204.01	8980.65	16184.66
Oxygen	46.37	62.3	108.66			
Outputs						
Industrial CO_2 emissions	-63.73	-85.63	-149.36			
Discarded stock	-28.34	-276.51	-304.84			
Dissipated energy				-8380.36	-10442.61	-16760.72
Δ in socio-economic stock	297.24	1920.64	2217.88			
Difference	0	0	0	0	0	0

Global physical stocks and related changes

Table 5: Physical stock-flow matrix in period 20 (matter = Gt, energy = EJ)

	Material reserves	Energy reserves	CO_2 concentration	Socio-economic stock
Initial stock	9451266.99	-201040.39	2101.05	40831.85
Resources converted into reserves	193156.73	1536.04		
CO_2 emissions			149.36	
Production of material goods				2522.72
Extraction/use of matter/energy	-2459.7	-16184.66		
Distruction of socio-ec. stock				-304.84
Final stock	9647311.66	-197232.48	2442.4	37174.38
Difference	0	0	0	0

Selected equations: households

- Total "real" consumption in each area is:

$$c^z = \alpha_1^z \cdot \frac{YD_w^z}{E(p_A^z)} + \alpha_2^z \cdot \frac{YD_c^z}{E(p_A^z)} + \alpha_3^z \cdot \frac{V_{-1}^z}{p_{A,-1}^z} \tag{1}$$

Selected equations: households

- Total "real" consumption in each area is:

$$c^z = \alpha_1^z \cdot \frac{YD_w^z}{E(p_A^z)} + \alpha_2^z \cdot \frac{YD_c^z}{E(p_A^z)} + \alpha_3^z \cdot \frac{V_{-1}^z}{p_{A,-1}^z} \tag{1}$$

- Households' total disposable income in each area is:

$$\begin{aligned} YD^z = {} & WB^z + DIV^z + FB^z + \\ & + r_{m,-1}^z \cdot M_{h,-1}^z + r_{b,-1}^z \cdot B_{s,z,-1}^z + xr_{-1}^f \cdot r_{b,-1}^f \cdot B_{s,z,-1}^f + \\ & + \Delta xr^f \cdot (B_{s,z,-1}^f + E_{s,z,-1}^f) - r_{h,-1}^z \cdot L_{h,-1}^z - T^z \end{aligned} \tag{2}$$

Selected equations: households

- Total "real" consumption in each area is:

$$c^z = \alpha_1^z \cdot \frac{YD_w^z}{E(p_A^z)} + \alpha_2^z \cdot \frac{YD_c^z}{E(p_A^z)} + \alpha_3^z \cdot \frac{V_{-1}^z}{p_{A,-1}^z} \tag{1}$$

- Households' total disposable income in each area is:

$$\begin{aligned} YD^z = {} & WB^z + DIV^z + FB^z + \\ & + r_{m,-1}^z \cdot M_{h,-1}^z + r_{b,-1}^z \cdot B_{s,z,-1}^z + xr_{-1}^f \cdot r_{b,-1}^f \cdot B_{s,z,-1}^f + \\ & + \Delta xr^f \cdot (B_{s,z,-1}^f + E_{s,z,-1}^f) - r_{h,-1}^z \cdot L_{h,-1}^z - T^z \end{aligned} \tag{2}$$

where the apex indicates the origin of the security, while the subscript indicates its destination.

Selected equations: households

- Total "real" consumption in each area is:

$$c^z = \alpha_1^z \cdot \frac{YD_w^z}{E(p_A^z)} + \alpha_2^z \cdot \frac{YD_c^z}{E(p_A^z)} + \alpha_3^z \cdot \frac{V_{-1}^z}{p_{A,-1}^z} \tag{1}$$

- Households' total disposable income in each area is:

$$\begin{aligned} YD^z = {} & WB^z + DIV^z + FB^z + \\ & + r_{m,-1}^z \cdot M_{h,-1}^z + r_{b,-1}^z \cdot B_{s,z,-1}^z + xr_{-1}^f \cdot r_{b,-1}^f \cdot B_{s,z,-1}^f + \\ & + \Delta xr^f \cdot (B_{s,z,-1}^f + E_{s,z,-1}^f) - r_{h,-1}^z \cdot L_{h,-1}^z - T^z \end{aligned} \tag{2}$$

where the apex indicates the origin of the security, while the subscript indicates its destination.

- Households' net wealth is:

$$V^z = V_{-1}^z + YD^z - c^z \cdot p_A^z \tag{3}$$

Selected equations: firms (current)

- Let us consider a 10×10 global production. The final demand vector of EU is:

$$\mathbf{d}^z = \begin{pmatrix} \beta_1^z \\ \vdots \\ \beta_{10}^z \end{pmatrix} \cdot c^z + \begin{pmatrix} \iota_1^z \\ \vdots \\ \iota_{10}^z \end{pmatrix} \cdot i_d^z + \begin{pmatrix} \sigma_1^z \\ \vdots \\ \sigma_{10}^z \end{pmatrix} \cdot gov^z + \begin{pmatrix} \eta_{1,z}^f \\ \vdots \\ \eta_{10,z}^f \end{pmatrix} \cdot exp^z - \begin{pmatrix} \eta_1^z \\ \vdots \\ \eta_{10}^z \end{pmatrix} \cdot imp^z \quad (4)$$

Selected equations: firms (current)

- Let us consider a 10×10 global production. The final demand vector of EU is:

$$\mathbf{d}^z = \begin{pmatrix} \beta_1^z \\ \vdots \\ \beta_{10}^z \end{pmatrix} \cdot c^z + \begin{pmatrix} \iota_1^z \\ \vdots \\ \iota_{10}^z \end{pmatrix} \cdot i_d^z + \begin{pmatrix} \sigma_1^z \\ \vdots \\ \sigma_{10}^z \end{pmatrix} \cdot gov^z + \begin{pmatrix} \eta_{1,z}^f \\ \vdots \\ \eta_{10,z}^f \end{pmatrix} \cdot exp^z - \begin{pmatrix} \eta_1^z \\ \vdots \\ \eta_{10}^z \end{pmatrix} \cdot imp^z \quad (4)$$

- The gross output vector is:

$$\mathbf{x}^z = \mathbf{A} \cdot \mathbf{x}^z + \mathbf{d}^z = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{d}^z, \; with : \mathbf{A} = \begin{pmatrix} a_{1,1} & \cdots & a_{1,10} \\ \dots & \ddots & \dots \\ a_{10,1} & \cdots & a_{10,10} \end{pmatrix} \quad (5)$$

Selected equations: firms (current)

- Let us consider a 10×10 global production. The final demand vector of EU is:

$$\mathbf{d}^z = \begin{pmatrix} \beta_1^z \\ \vdots \\ \beta_{10}^z \end{pmatrix} \cdot c^z + \begin{pmatrix} \iota_1^z \\ \vdots \\ \iota_{10}^z \end{pmatrix} \cdot i_d^z + \begin{pmatrix} \sigma_1^z \\ \vdots \\ \sigma_{10}^z \end{pmatrix} \cdot gov^z + \begin{pmatrix} \eta_{1,z}^f \\ \vdots \\ \eta_{10,z}^f \end{pmatrix} \cdot exp^z - \begin{pmatrix} \eta_1^z \\ \vdots \\ \eta_{10}^z \end{pmatrix} \cdot imp^z \quad (4)$$

- The gross output vector is:

$$\mathbf{x}^z = \mathbf{A} \cdot \mathbf{x}^z + \mathbf{d}^z = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{d}^z, \ with : \mathbf{A} = \begin{pmatrix} a_{1,1} & \cdots & a_{1,10} \\ \dots & \ddots & \dots \\ a_{10,1} & \cdots & a_{10,10} \end{pmatrix} \quad (5)$$

- The value added in each area is:

$$YN^z = c^z \cdot p_A^z + i_d^z \cdot p_I^z + gov^z \cdot p_G^z + EXP^z - IMP^z - VAT^z - TAR^z \quad (6)$$

Selected equations: consumer choices

- The share of manufacturing products to total consumption is stable:

$$\beta_1^z = \bar{\beta}_1^z \tag{7}$$

Selected equations: consumer choices

- The share of manufacturing products to total consumption is stable:

$$\beta_1^z = \bar{\beta}_1^z \tag{7}$$

- The share of services to total consumption increases as disposable incomes (expressed in real terms, using the price of services) increase:

$$\beta_3^z = \beta_{3,-1}^z + \beta_{31}^z \cdot \frac{YD_{w,-1}^z}{p_{3,-1}^z} + \beta_{32}^z \cdot \frac{YD_{c,-1}^z}{p_{3,-1}^z} \tag{8}$$

Selected equations: consumer choices

- The share of manufacturing products to total consumption is stable:

$$\beta_1^z = \bar{\beta}_1^z \tag{7}$$

- The share of services to total consumption increases as disposable incomes (expressed in real terms, using the price of services) increase:

$$\beta_3^z = \beta_{3,-1}^z + \beta_{31}^z \cdot \frac{YD_{w,-1}^z}{p_{3,-1}^z} + \beta_{32}^z \cdot \frac{YD_{c,-1}^z}{p_{3,-1}^z} \tag{8}$$

- The share of agricultural products is calculated residually, and tends to decline as the economy grows:

$$\beta_2^z = 1 - \beta_1^z - \beta_3^z \tag{9}$$

with $\beta_2^z \geq 0$.

Selected equations: firms (capital)

- The target stock of fixed capital depends on industry-specific target capital to output ratios:

$$k^{z*} = \mathbf{p}_{-1}^{zT} \cdot \left[\mathbf{h}^{z} \odot (\mathbf{x}_{-1}^{z} + \mathbf{x}_{-1}^{f})\right] \cdot \frac{1}{p_{I,-1}^{z}} \tag{10}$$

Selected equations: firms (capital)

- The target stock of fixed capital depends on industry-specific target capital to output ratios:

$$k^{z*} = \mathbf{p}_{-1}^{zT} \cdot \left[\mathbf{h}^{z} \odot (\mathbf{x}_{-1}^{z} + \mathbf{x}_{-1}^{f})\right] \cdot \frac{1}{p_{I,-1}^{z}} \tag{10}$$

The real gross investment is:

$$i_{d}^{z} = \gamma^{z} \cdot (k^{z*} - k_{-1}^{z}) + \delta^{z} \cdot k_{-1}^{z} \tag{11}$$

Selected equations: firms (capital)

- The target stock of fixed capital depends on industry-specific target capital to output ratios:

$$k^{z*} = \mathbf{p}_{-1}^{zT} \cdot \left[\mathbf{h}^z \odot (\mathbf{x}_{-1}^z + \mathbf{x}_{-1}^f)\right] \cdot \frac{1}{p_{I,-1}^z} \tag{10}$$

The real gross investment is:

$$i_d^z = \gamma^z \cdot (k^{z*} - k_{-1}^z) + \delta^z \cdot k_{-1}^z \tag{11}$$

- The end-of-period stock of bank loans is defined residually:

$$L_F^z = L_{F,-1}^z + i_d^z \cdot p_I^z - AF^z - FF_u^z - \Delta E_s^z \tag{12}$$

where:

$$AF^z = \delta^z \cdot k_{-1}^z \cdot p_I^z - k^z \cdot \Delta p_I^z$$

Selected equations: commercial banks

- The supply of bank loans is:

$$L_s^z = L_F^z + L_h^z \tag{13}$$

Selected equations: commercial banks

- The supply of bank loans is:

$$L_s^z = L_F^z + L_h^z \tag{13}$$

- where the demand for personal loans is defined as:

$$L_h^z = L_{h,-1}^z \cdot (1 - \psi_1^z) + \max\left[c^z \cdot p_A^z - YD^z, \psi_2^z \cdot \Delta(\mathbf{p}^{zT} \cdot \mathbf{dc}^z)\right] \tag{14}$$

Selected equations: commercial banks

- The supply of bank loans is:

$$L_s^z = L_F^z + L_h^z \tag{13}$$

- where the demand for personal loans is defined as:

$$L_h^z = L_{h,-1}^z \cdot (1 - \psi_1^z) + \max\left[c^z \cdot p_A^z - YD^z, \psi_2^z \cdot \Delta(\mathbf{p}^{zT} \cdot \mathbf{dc}^z)\right] \tag{14}$$

- The supply of bank deposits is:

$$M_s^z = M_h^z \tag{15}$$

Selected equations: labour market and popul.

- The employment generated by demand of (domestic and foreign) industries is:

$$N^z = \mathbf{x}^{zT} \cdot \mathbf{l}^z = \sum N_j^z \tag{16}$$

Selected equations: labour market and popul.

- The employment generated by demand of (domestic and foreign) industries is:

$$N^z = \mathbf{x}^{zT} \cdot \mathbf{l}^z = \sum N_j^z \tag{16}$$

- The available labour force in each area is:

$$\mathbf{POP}^z = \mathbf{POP}^z_{-1} \odot (I + \mathbf{g}^z_{pop}) + \mathbf{IMM}^z - \mathbf{IMM}^f \tag{17}$$

Selected equations: labour market and popul.

- The employment generated by demand of (domestic and foreign) industries is:

$$N^z = \mathbf{x}^{zT} \cdot \mathbf{l}^z = \sum N_j^z \tag{16}$$

- The available labour force in each area is:

$$\mathbf{POP}^z = \mathbf{POP}^z_{-1} \odot (I + \mathbf{g}^z_{pop}) + \mathbf{IMM}^z - \mathbf{IMM}^f \tag{17}$$

- Immigration inflow in each area is:

$$\mathbf{IMM}^z = \gamma^z_{imm,0} \odot \mathbf{POP}^f_{-1} + \gamma^z_{imm,1} \odot \mathbf{un}^f_{-1} + \gamma^z_{imm,2} \odot (\mathbf{w}^z_{-1} - \mathbf{w}^f_{-1}) \tag{18}$$

Selected equations: labour market and popul.

- The employment generated by demand of (domestic and foreign) industries is:

$$N^z = \mathbf{x}^{zT} \cdot \mathbf{l}^z = \sum N_j^z \tag{16}$$

- The available labour force in each area is:

$$\mathbf{POP}^z = \mathbf{POP}^z_{-1} \odot (I + \mathbf{g}^z_{pop}) + \mathbf{IMM}^z - \mathbf{IMM}^f \tag{17}$$

- Immigration inflow in each area is:

$$\mathbf{IMM}^z = \gamma^z_{imm,0} \odot \mathbf{POP}^f_{-1} + \gamma^z_{imm,1} \odot \mathbf{un}^f_{-1} + \gamma^z_{imm,2} \odot (\mathbf{w}^z_{-1} - \mathbf{w}^f_{-1}) \tag{18}$$

- In each industry, the percentage of female workers (gender segregation) is:

$$\rho^z_j = \rho^z_{0j} - \rho^z_{1j} \cdot (w^z_j - w^z_{j,-1}) \tag{19}$$

Selected equations: government and CB

- The government budget deficit in each area is:

$$DEF_g^z = gov^z \cdot p_G^z + r_{b,-1}^z \cdot B_{s,-1}^z - F_{cb}^z - T^z - VAT^z - TAR^z \tag{20}$$

Selected equations: government and CB

- The government budget deficit in each area is:

$$DEF_g^z = gov^z \cdot p_G^z + r_{b,-1}^z \cdot B_{s,-1}^z - F_{cb}^z - T^z - VAT^z - TAR^z \tag{20}$$

- Therefore, the supply of government bills is:

$$B_s^z = B_{s,-1}^z + DEF_g^z \tag{21}$$

Selected equations: government and CB

- The government budget deficit in each area is:

$$DEF_g^z = gov^z \cdot p_G^z + r_{b,-1}^z \cdot B_{s,-1}^z - F_{cb}^z - T^z - VAT^z - TAR^z \tag{20}$$

- Therefore, the supply of government bills is:

$$B_s^z = B_{s,-1}^z + DEF_g^z \tag{21}$$

- The amount of domestic bills held by the central bank of the first area is:

$$B_{cb,z}^z = \Delta H_s^z - \Delta A_s^z - xr^f \cdot \Delta B_{cb,s,z}^f \tag{22}$$

Selected equations: government and CB

- The government budget deficit in each area is:

$$DEF_g^z = gov^z \cdot p_G^z + r_{b,-1}^z \cdot B_{s,-1}^z - F_{cb}^z - T^z - VAT^z - TAR^z \tag{20}$$

- Therefore, the supply of government bills is:

$$B_s^z = B_{s,-1}^z + DEF_g^z \tag{21}$$

- The amount of domestic bills held by the central bank of the first area is:

$$B_{cb,z}^z = \Delta H_s^z - \Delta A_s^z - xr^f \cdot \Delta B_{cb,s,z}^f \tag{22}$$

- Cash supply adjusts to households' demand:

$$H_s^z = H_h^z \tag{23}$$

Selected equations: prices

- Firms use a mark-up rule. The unit price of production vector is:

$$\mathbf{p}^{z*} = \mathbf{w}^{z} \odot \mathbf{l}^{z} + \mathbf{p}^{z*} \cdot \mathbf{A} \odot \mathbf{m}^{z*} \odot \mathbf{h}_{d}^{z} \tag{24}$$

Selected equations: prices

- Firms use a mark-up rule. The unit price of production vector is:

$$\mathbf{p}^{z*} = \mathbf{w}^{z} \odot \mathbf{l}^{z} + \mathbf{p}^{z*} \cdot \mathbf{A} \odot \mathbf{m}^{z*} \odot \mathbf{h}_{d}^{z} \tag{24}$$

- However, market prices also depend on labour-constrained potential output, vat and tariffs:

$$\mathbf{p}^{z} = \left[\mathbf{p}^{z*} + \Gamma_{x}^{z} \odot (\mathbf{x}_{-1}^{z} - \mathbf{x}_{-1}^{z*})\right] \odot \left[\begin{pmatrix} 1 \\ \vdots \\ 1 \end{pmatrix} + \tau_{vat}^{z} + \tau_{tar}^{f}\right] \tag{25}$$

Selected equations: prices

- Firms use a mark-up rule. The unit price of production vector is:

$$\mathbf{p}^{z*} = \mathbf{w}^{z} \odot \mathbf{l}^{z} + \mathbf{p}^{z*} \cdot \mathbf{A} \odot \mathbf{m}^{z*} \odot \mathbf{h}_{d}^{z} \tag{24}$$

- However, market prices also depend on labour-constrained potential output, vat and tariffs:

$$\mathbf{p}^{z} = \left[\mathbf{p}^{z*} + \Gamma_{x}^{z} \odot (\mathbf{x}_{-1}^{z} - \mathbf{x}_{-1}^{z*})\right] \odot \left[\begin{pmatrix} 1 \\ \vdots \\ 1 \end{pmatrix} + \tau_{vat}^{z} + \tau_{tar}^{f}\right] \tag{25}$$

- The consumer price index or average price of consumption is:

$$p_{A}^{z} = \mathbf{p}^{z\mathcal{T}} \cdot \beta^{z} \tag{26}$$

Selected equations: portfolio choices

- Households' demand for domestic bills is:

$$\frac{B^z_{h,z}}{V^z} = \lambda_{10} + \lambda_{11} \cdot r^z_{b,-1} - \lambda_{12} \cdot \left(r^f_{b,-1} + \frac{\Delta x r^f}{x r^f} \right) - \lambda_{13} \cdot r^z_{m,-1} - \lambda_{14} \cdot \frac{YD^z}{V^z} + \\ - \lambda_{15} \cdot r^z_{e,-1} - \lambda_{16} \cdot \left(r^f_{e,-1} + \frac{\Delta x r^f}{x r^f} \right) \tag{27}$$

Selected equations: portfolio choices

- Households' demand for domestic bills is:

$$\frac{B^z_{h,z}}{V^z} = \lambda_{10} + \lambda_{11} \cdot r^z_{b,-1} - \lambda_{12} \cdot \left(r^f_{b,-1} + \frac{\Delta x r^f}{x r^f} \right) - \lambda_{13} \cdot r^z_{m,-1} - \lambda_{14} \cdot \frac{YD^z}{V^z} + \\ - \lambda_{15} \cdot r^z_{e,-1} - \lambda_{16} \cdot \left(r^f_{e,-1} + \frac{\Delta x r^f}{x r^f} \right) \tag{27}$$

- Households' demand for cash is:

$$H^z_h = \lambda^z_c \cdot c^z_{-1} \cdot p^z_{A,-1} \tag{28}$$

Selected equations: portfolio choices

- Households' demand for domestic bills is:

$$\frac{B^z_{h,z}}{V^z} = \lambda_{10} + \lambda_{11} \cdot r^z_{b,-1} - \lambda_{12} \cdot \left(r^f_{b,-1} + \frac{\Delta xr^f}{xr^f} \right) - \lambda_{13} \cdot r^z_{m,-1} - \lambda_{14} \cdot \frac{YD^z}{V^z} + \\ - \lambda_{15} \cdot r^z_{e,-1} - \lambda_{16} \cdot \left(r^f_{e,-1} + \frac{\Delta xr^f}{xr^f} \right) \tag{27}$$

- Households' demand for cash is:

$$H^z_h = \lambda^z_c \cdot c^z_{-1} \cdot p^z_{A,-1} \tag{28}$$

- Bank deposits are the buffer stock:

$$M^z_h = V^z + L^z_h - H^z_h - B^z_{h,z} - B^f_{h,z} - E^z_{h,z} - E^f_{h,z} \tag{29}$$

Selected equations: portfolio choices

- Households' demand for domestic bills is:

$$\frac{B^z_{h,z}}{V^z} = \lambda_{10} + \lambda_{11} \cdot r^z_{b,-1} - \lambda_{12} \cdot \left(r^f_{b,-1} + \frac{\Delta x r^f}{x r^f} \right) - \lambda_{13} \cdot r^z_{m,-1} - \lambda_{14} \cdot \frac{YD^z}{V^z} + \\ - \lambda_{15} \cdot r^z_{e,-1} - \lambda_{16} \cdot \left(r^f_{e,-1} + \frac{\Delta x r^f}{x r^f} \right) \tag{27}$$

- Households' demand for cash is:

$$H^z_h = \lambda^z_c \cdot c^z_{-1} \cdot p^z_{A,-1} \tag{28}$$

- Bank deposits are the buffer stock:

$$M^z_h = V^z + L^z_h - H^z_h - B^z_{h,z} - B^f_{h,z} - E^z_{h,z} - E^f_{h,z} \tag{29}$$

- The redundant equation is:

$$B^z_{cb,z} = B^z_s - B^z_{s,z} - B^z_{s,f} - B^z_b$$

Figure 2. Sankey diagram of transactions (in $t = 20$)

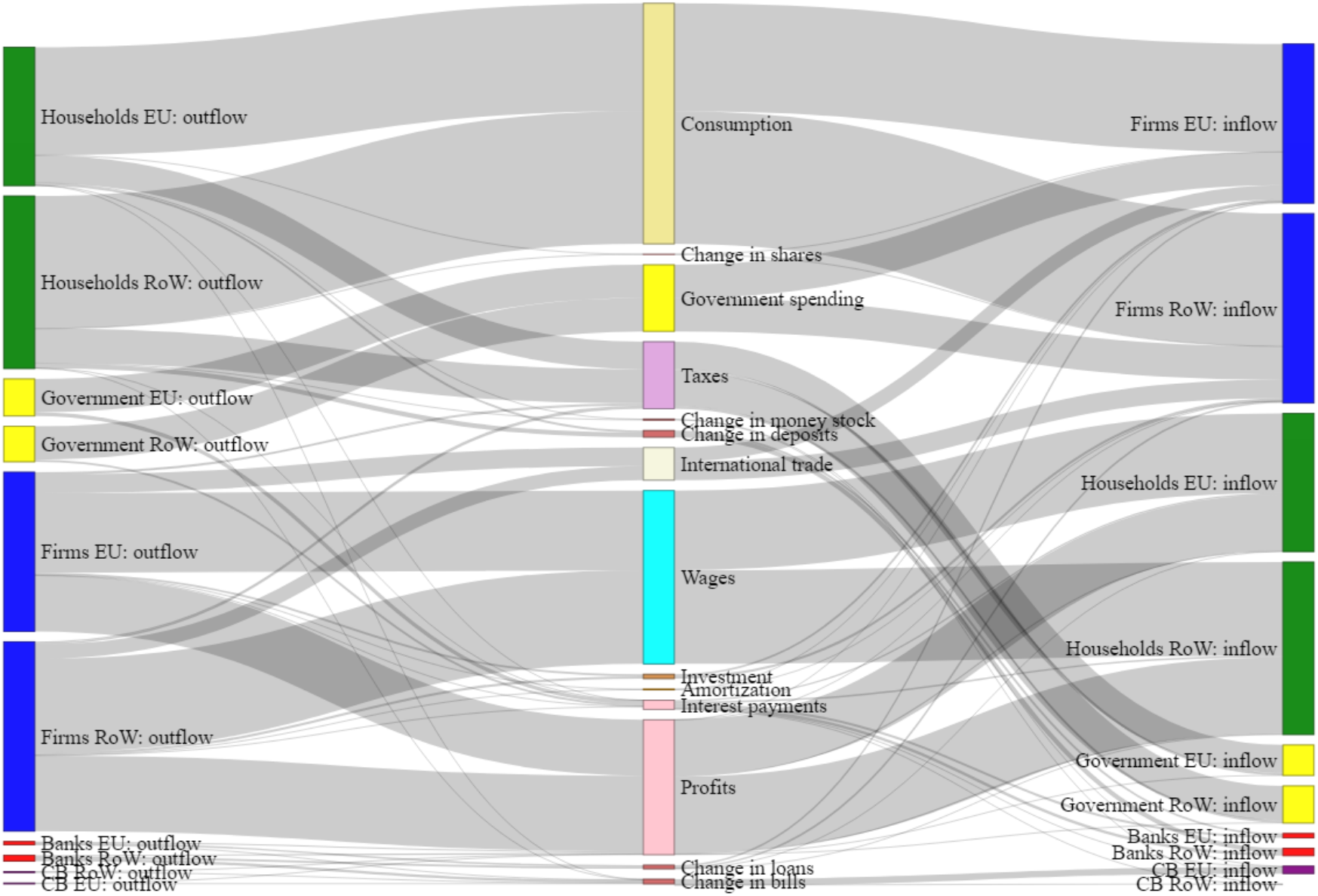


Figure 3. Cross-industry input-output flows (in $t = 20$)

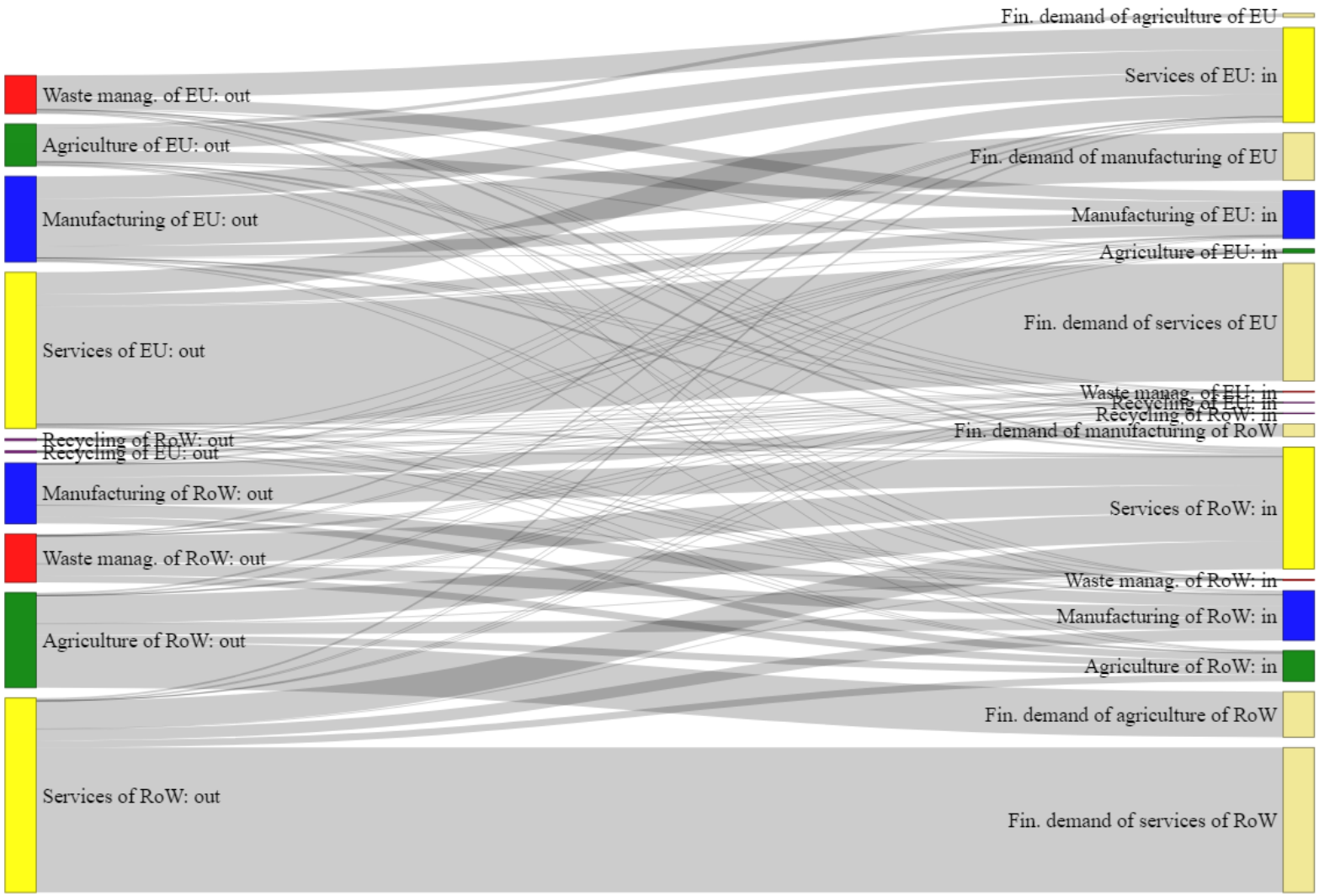


Figure 4. Physical flows of matter and energy (in $t = 20$)

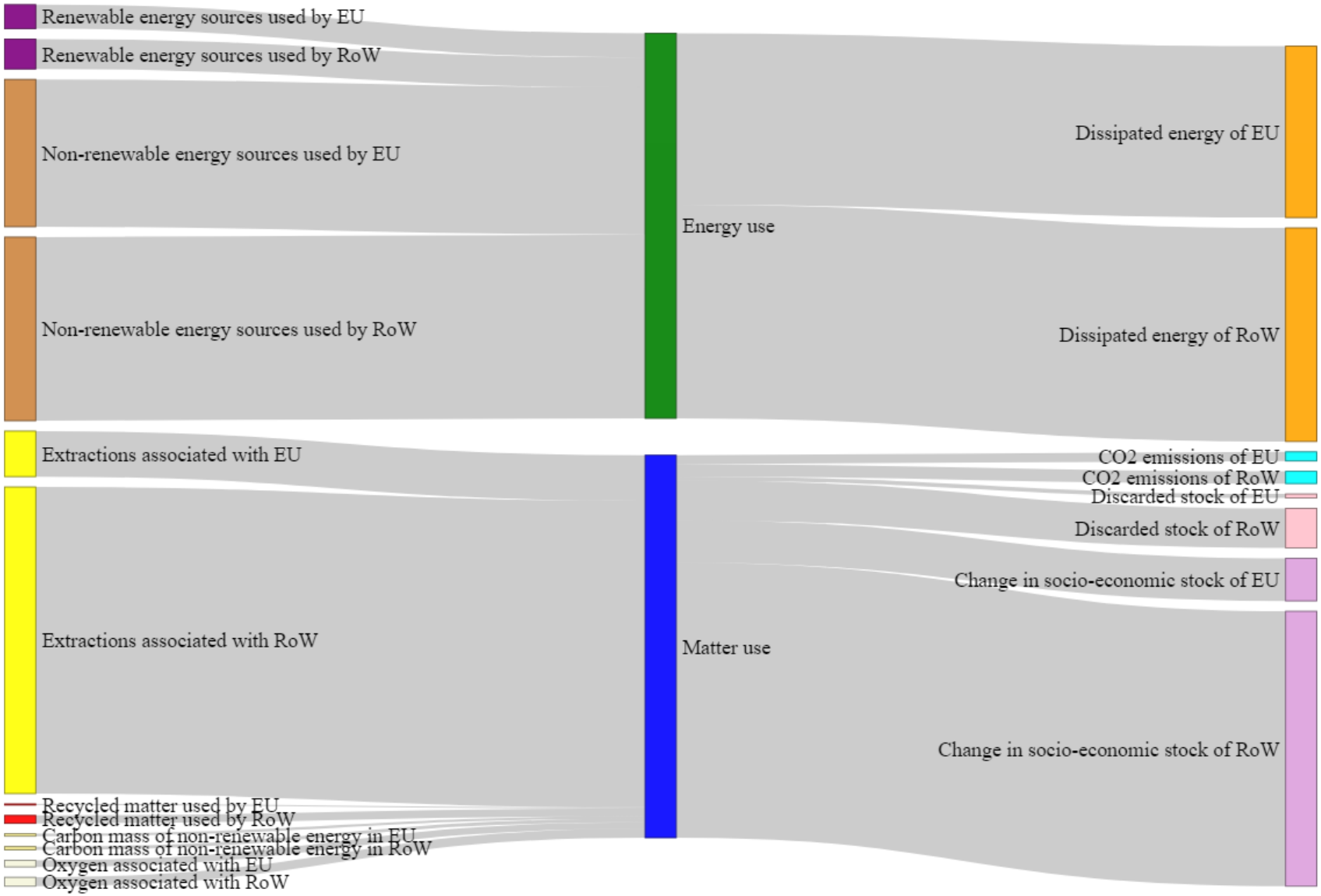


Figure 5. Adjustment of selected variables to steady state

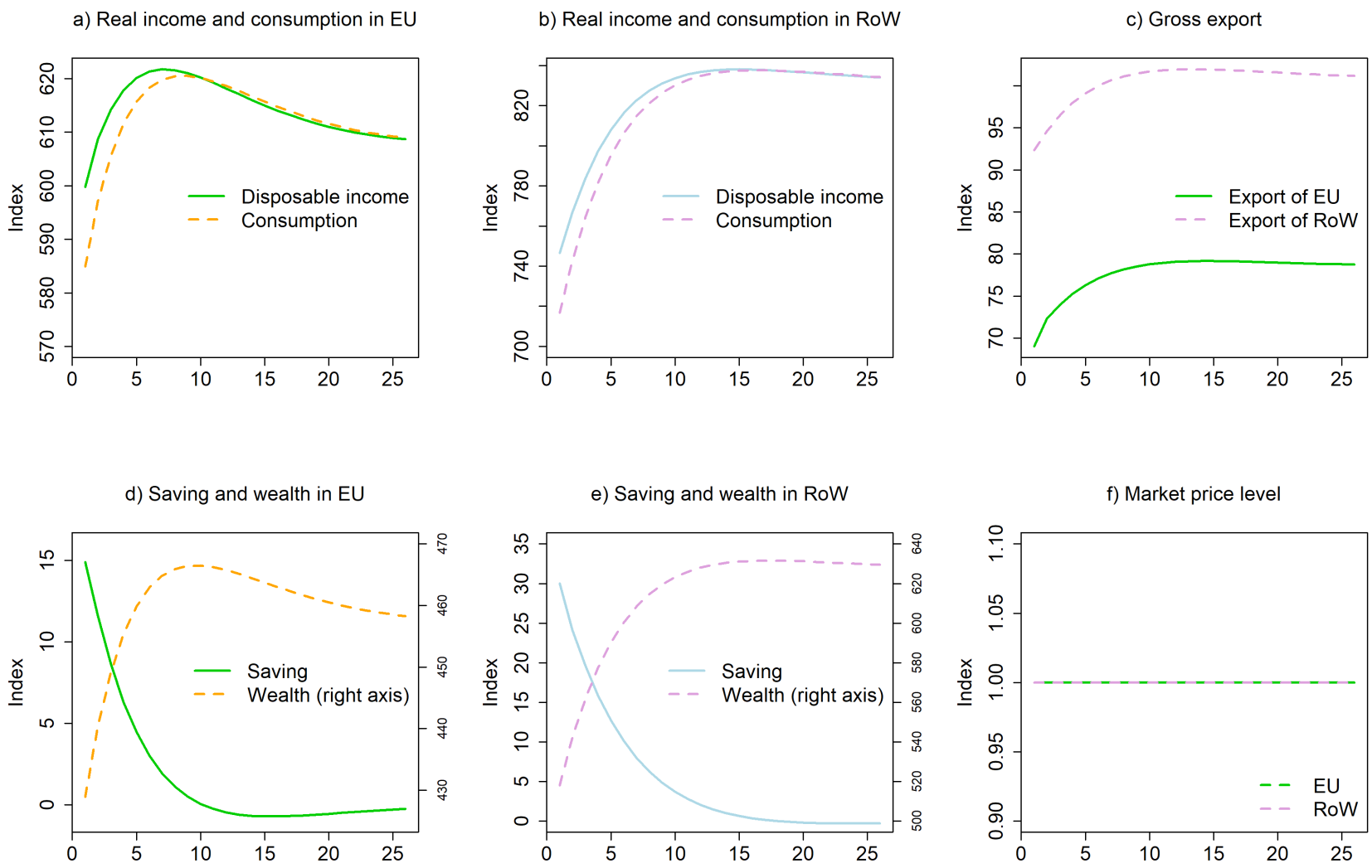
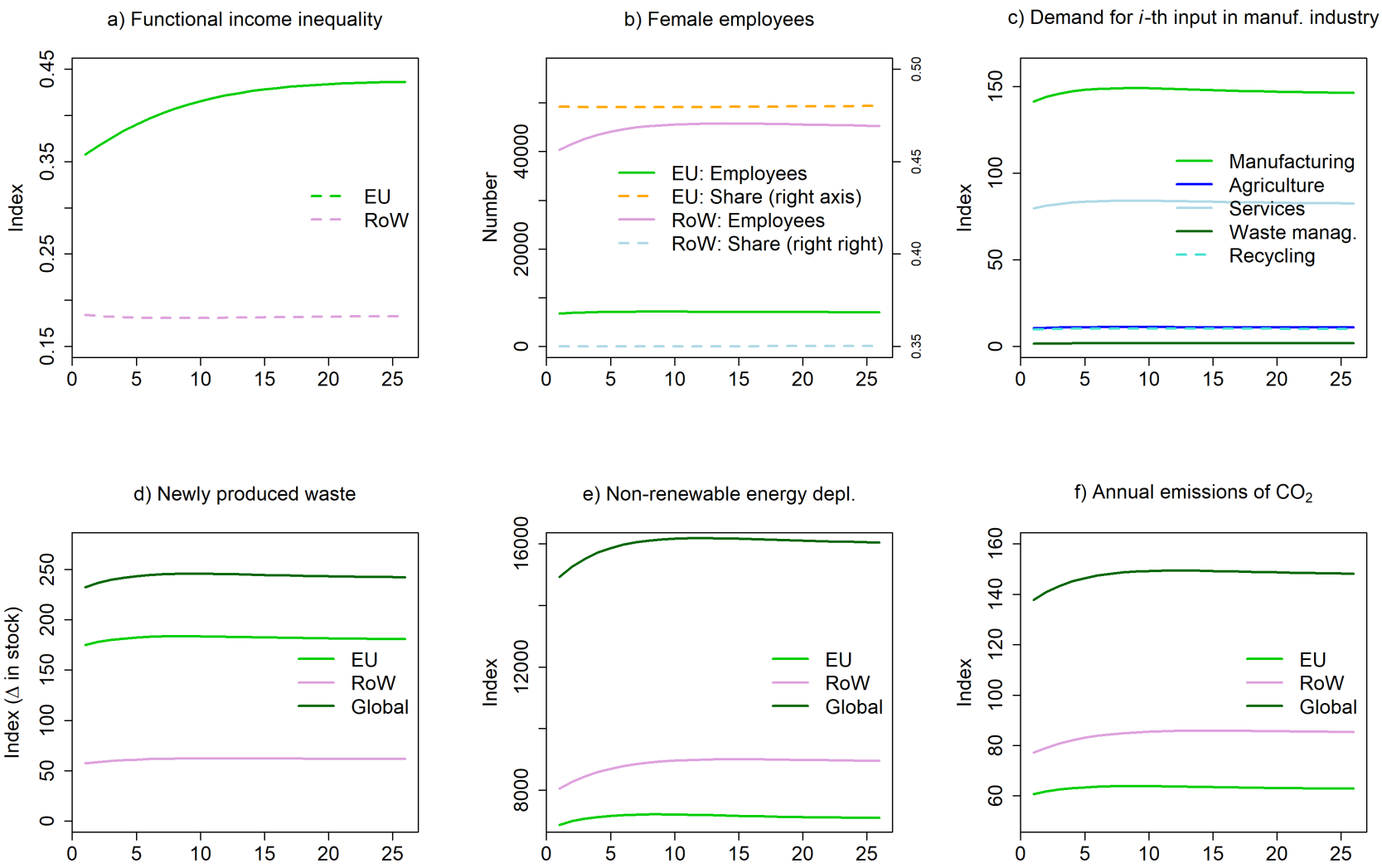


Figure 6. Adjustment of selected variables to steady state



The circular economy (CE)

- CE = policies that aim at reusing, repairing, sharing, and recycling products and resources to create a closed-loop system, thus minimising waste, pollution, and CO_2 emissions

The circular economy (CE)

- CE = policies that aim at reusing, repairing, sharing, and recycling products and resources to create a closed-loop system, thus minimising waste, pollution, and CO_2 emissions
- If waste is not recycled, the global matrix of technical coefficients is:

$$\mathbf{A} = \left(\begin{array}{ccccc|ccccc} a_{11} & a_{12} & a_{13} & a_{14} & 0 & a_{16} & a_{17} & a_{18} & a_{19} & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} & 0 & a_{26} & a_{27} & a_{28} & a_{29} & 0 \\ a_{31} & a_{32} & a_{33} & a_{34} & 0 & a_{36} & a_{37} & a_{38} & a_{39} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & a_{46} & a_{47} & a_{48} & a_{49} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \hline a_{61} & a_{62} & a_{63} & a_{64} & 0 & a_{66} & a_{67} & a_{68} & a_{69} & 0 \\ a_{71} & a_{72} & a_{73} & a_{74} & 0 & a_{76} & a_{77} & a_{78} & a_{79} & 0 \\ a_{81} & a_{82} & a_{83} & a_{84} & 0 & a_{86} & a_{87} & a_{88} & a_{89} & 0 \\ a_{91} & a_{92} & a_{93} & a_{94} & 0 & a_{96} & a_{97} & a_{98} & a_{99} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right)$$

The circular economy (CE)

- CE = policies that aim at reusing, repairing, sharing, and recycling products and resources to create a closed-loop system, thus minimising waste, pollution, and CO_2 emissions
- If waste is not recycled, the global matrix of technical coefficients is:

$$\mathbf{A} = \left(\begin{array}{ccccc|ccccc} a_{11} & a_{12} & a_{13} & a_{14} & 0 & a_{16} & a_{17} & a_{18} & a_{19} & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} & 0 & a_{26} & a_{27} & a_{28} & a_{29} & 0 \\ a_{31} & a_{32} & a_{33} & a_{34} & 0 & a_{36} & a_{37} & a_{38} & a_{39} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & a_{46} & a_{47} & a_{48} & a_{49} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \hline a_{61} & a_{62} & a_{63} & a_{64} & 0 & a_{66} & a_{67} & a_{68} & a_{69} & 0 \\ a_{71} & a_{72} & a_{73} & a_{74} & 0 & a_{76} & a_{77} & a_{78} & a_{79} & 0 \\ a_{81} & a_{82} & a_{83} & a_{84} & 0 & a_{86} & a_{87} & a_{88} & a_{89} & 0 \\ a_{91} & a_{92} & a_{93} & a_{94} & 0 & a_{96} & a_{97} & a_{98} & a_{99} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right)$$

- A CE innovation implies a change in technical coefficients...

A simple CE innovation in EU

- The new matrix will be:

$$\mathbf{A'} = \left(\begin{array}{ccccc||ccccc}
a'_{11} \leq a_{11} & a'_{12} \leq a_{12} & a'_{13} \leq a_{13} & a'_{14} \leq a'_{14} & a'_{15} > 0 & a_{16} & a_{17} & a_{18} & a_{19} & 0 \\
a'_{21} \leq a_{21} & a'_{22} \leq a_{22} & a'_{23} \leq a_{23} & a'_{24} \leq a'_{24} & a'_{25} > 0 & a_{26} & a_{27} & a_{28} & a_{29} & 0 \\
a'_{31} \leq a_{31} & a'_{32} \leq a_{32} & a'_{33} \leq a_{33} & a'_{34} \leq a'_{34} & a'_{35} > 0 & a_{36} & a_{37} & a_{38} & a_{39} & 0 \\
a'_{41} \leq a_{41} & a'_{42} \leq a_{42} & a'_{43} \leq a_{43} & a'_{44} \leq a'_{44} & a'_{45} > 0 & a_{46} & a_{47} & a_{48} & a_{49} & 0 \\
a'_{51} > 0 & a'_{52} > 0 & a'_{53} > 0 & a'_{54} > 0 & 0 & a_{56} & a_{57} & a_{58} & a_{59} & 0 \\
\hline
a'_{61} \leq a_{61} & a'_{62} \leq a_{62} & a'_{63} \leq a_{63} & a'_{64} \leq a'_{64} & a'_{65} > 0 & a_{66} & a_{67} & a_{68} & a_{69} & 0 \\
a'_{71} \leq a_{71} & a'_{72} \leq a_{72} & a'_{73} \leq a_{73} & a'_{74} \leq a'_{74} & a'_{75} > 0 & a_{76} & a_{77} & a_{78} & a_{79} & 0 \\
a'_{81} \leq a_{81} & a'_{82} \leq a_{82} & a'_{83} \leq a_{83} & a'_{84} \leq a'_{84} & a'_{85} > 0 & a_{86} & a_{87} & a_{88} & a_{89} & 0 \\
a'_{91} \leq a_{91} & a'_{92} \leq a_{92} & a'_{93} \leq a_{93} & a'_{94} \leq a'_{94} & a'_{95} > 0 & a_{96} & a_{97} & a_{98} & a_{99} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}\right)$$

A simple CE innovation in EU

- The new matrix will be:

$$\mathbf{A'} = \left(\begin{array}{ccccc||ccccc} a'_{11} \leq a_{11} & a'_{12} \leq a_{12} & a'_{13} \leq a_{13} & a'_{14} \leq a'_{14} & a'_{15} > 0 & a_{16} & a_{17} & a_{18} & a_{19} & 0 \\ a'_{21} \leq a_{21} & a'_{22} \leq a_{22} & a'_{23} \leq a_{23} & a'_{24} \leq a'_{24} & a'_{25} > 0 & a_{26} & a_{27} & a_{28} & a_{29} & 0 \\ a'_{31} \leq a_{31} & a'_{32} \leq a_{32} & a'_{33} \leq a_{33} & a'_{34} \leq a'_{34} & a'_{35} > 0 & a_{36} & a_{37} & a_{38} & a_{39} & 0 \\ a'_{41} \leq a_{41} & a'_{42} \leq a_{42} & a'_{43} \leq a_{43} & a'_{44} \leq a'_{44} & a'_{45} > 0 & a_{46} & a_{47} & a_{48} & a_{49} & 0 \\ a'_{51} > 0 & a'_{52} > 0 & a'_{53} > 0 & a'_{54} > 0 & 0 & a_{56} & a_{57} & a_{58} & a_{59} & 0 \\ \hline a'_{61} \leq a_{61} & a'_{62} \leq a_{62} & a'_{63} \leq a_{63} & a'_{64} \leq a'_{64} & a'_{65} > 0 & a_{66} & a_{67} & a_{68} & a_{69} & 0 \\ a'_{71} \leq a_{71} & a'_{72} \leq a_{72} & a'_{73} \leq a_{73} & a'_{74} \leq a'_{74} & a'_{75} > 0 & a_{76} & a_{77} & a_{78} & a_{79} & 0 \\ a'_{81} \leq a_{81} & a'_{82} \leq a_{82} & a'_{83} \leq a_{83} & a'_{84} \leq a'_{84} & a'_{85} > 0 & a_{86} & a_{87} & a_{88} & a_{89} & 0 \\ a'_{91} \leq a_{91} & a'_{92} \leq a_{92} & a'_{93} \leq a_{93} & a'_{94} \leq a'_{94} & a'_{95} > 0 & a_{96} & a_{97} & a_{98} & a_{99} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right)$$

- Fall in coefficients defining the quantities of manufacturing and agricultural products and services used as inputs in first area ($\bullet$)

A simple CE innovation in EU

- The new matrix will be:

$$\mathbf{A'} = \left(\begin{array}{ccccc||ccccc} a'_{11} \leq a_{11} & a'_{12} \leq a_{12} & a'_{13} \leq a_{13} & a'_{14} \leq a'_{14} & a'_{15} > 0 & a_{16} & a_{17} & a_{18} & a_{19} & 0 \\ a'_{21} \leq a_{21} & a'_{22} \leq a_{22} & a'_{23} \leq a_{23} & a'_{24} \leq a'_{24} & a'_{25} > 0 & a_{26} & a_{27} & a_{28} & a_{29} & 0 \\ a'_{31} \leq a_{31} & a'_{32} \leq a_{32} & a'_{33} \leq a_{33} & a'_{34} \leq a'_{34} & a'_{35} > 0 & a_{36} & a_{37} & a_{38} & a_{39} & 0 \\ a'_{41} \leq a_{41} & a'_{42} \leq a_{42} & a'_{43} \leq a_{43} & a'_{44} \leq a'_{44} & a'_{45} > 0 & a_{46} & a_{47} & a_{48} & a_{49} & 0 \\ a'_{51} > 0 & a'_{52} > 0 & a'_{53} > 0 & a'_{54} > 0 & 0 & a_{56} & a_{57} & a_{58} & a_{59} & 0 \\ \hline a'_{61} \leq a_{61} & a'_{62} \leq a_{62} & a'_{63} \leq a_{63} & a'_{64} \leq a'_{64} & a'_{65} > 0 & a_{66} & a_{67} & a_{68} & a_{69} & 0 \\ a'_{71} \leq a_{71} & a'_{72} \leq a_{72} & a'_{73} \leq a_{73} & a'_{74} \leq a'_{74} & a'_{75} > 0 & a_{76} & a_{77} & a_{78} & a_{79} & 0 \\ a'_{81} \leq a_{81} & a'_{82} \leq a_{82} & a'_{83} \leq a_{83} & a'_{84} \leq a'_{84} & a'_{85} > 0 & a_{86} & a_{87} & a_{88} & a_{89} & 0 \\ a'_{91} \leq a_{91} & a'_{92} \leq a_{92} & a'_{93} \leq a_{93} & a'_{94} \leq a'_{94} & a'_{95} > 0 & a_{96} & a_{97} & a_{98} & a_{99} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right)$$

- Fall in coefficients defining the quantities of manufacturing and agricultural products and services used as inputs in first area (•)
- Domestic waste now enters the production process in first area (•)

A simple CE innovation in EU

- The new matrix will be:

$$\mathbf{A'} = \left(\begin{array}{ccccc|ccccc} a'_{11} \leq a_{11} & a'_{12} \leq a_{12} & a'_{13} \leq a_{13} & a'_{14} \leq a'_{14} & a'_{15} > 0 & a_{16} & a_{17} & a_{18} & a_{19} & 0 \\ a'_{21} \leq a_{21} & a'_{22} \leq a_{22} & a'_{23} \leq a_{23} & a'_{24} \leq a'_{24} & a'_{25} > 0 & a_{26} & a_{27} & a_{28} & a_{29} & 0 \\ a'_{31} \leq a_{31} & a'_{32} \leq a_{32} & a'_{33} \leq a_{33} & a'_{34} \leq a'_{34} & a'_{35} > 0 & a_{36} & a_{37} & a_{38} & a_{39} & 0 \\ a'_{41} \leq a_{41} & a'_{42} \leq a_{42} & a'_{43} \leq a_{43} & a'_{44} \leq a'_{44} & a'_{45} > 0 & a_{46} & a_{47} & a_{48} & a_{49} & 0 \\ a'_{51} > 0 & a'_{52} > 0 & a'_{53} > 0 & a'_{54} > 0 & 0 & a_{56} & a_{57} & a_{58} & a_{59} & 0 \\ \hline a'_{61} \leq a_{61} & a'_{62} \leq a_{62} & a'_{63} \leq a_{63} & a'_{64} \leq a'_{64} & a'_{65} > 0 & a_{66} & a_{67} & a_{68} & a_{69} & 0 \\ a'_{71} \leq a_{71} & a'_{72} \leq a_{72} & a'_{73} \leq a_{73} & a'_{74} \leq a'_{74} & a'_{75} > 0 & a_{76} & a_{77} & a_{78} & a_{79} & 0 \\ a'_{81} \leq a_{81} & a'_{82} \leq a_{82} & a'_{83} \leq a_{83} & a'_{84} \leq a'_{84} & a'_{85} > 0 & a_{86} & a_{87} & a_{88} & a_{89} & 0 \\ a'_{91} \leq a_{91} & a'_{92} \leq a_{92} & a'_{93} \leq a_{93} & a'_{94} \leq a'_{94} & a'_{95} > 0 & a_{96} & a_{97} & a_{98} & a_{99} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right)$$

- Fall in coefficients defining the quantities of manufacturing and agricultural products and services used as inputs in first area (•)
- Domestic waste now enters the production process in first area (•)
- Manufacturing and agricultural products and services are used as inputs in waste industry of first area (•)

The role of the government sector

- There is a tendency for current technical coefficients to converge to target CE values over time:

$$a_{ij} = a_{ij,-1} + \gamma_A^z \cdot (a'_{ij,-1} - a_{ij,-1}) \tag{30}$$

The role of the government sector

- There is a tendency for current technical coefficients to converge to target CE values over time:

$$a_{ij} = a_{ij,-1} + \gamma_A^z \cdot (a'_{ij,-1} - a_{ij,-1}) \tag{30}$$

where γ_A is defined as:

$$\gamma_A^z = \gamma_{A0}^z + \Gamma_A^{zT} \cdot \sigma^z \cdot gov_{-1}^z \tag{31}$$

The role of the government sector

- There is a tendency for current technical coefficients to converge to target CE values over time:

$$a_{ij} = a_{ij,-1} + \gamma_A^z \cdot (a'_{ij,-1} - a_{ij,-1}) \tag{30}$$

where γ_A is defined as:

$$\gamma_A^z = \gamma_{A0}^z + \Gamma_A^{zT} \cdot \sigma^z \cdot gov_{-1}^z \tag{31}$$

- The average speed of convergence of technical coefficients to their target values is a linear, positive function of industry-specific government expenditures

Figure 6. CE-oriented gov. spending in EU

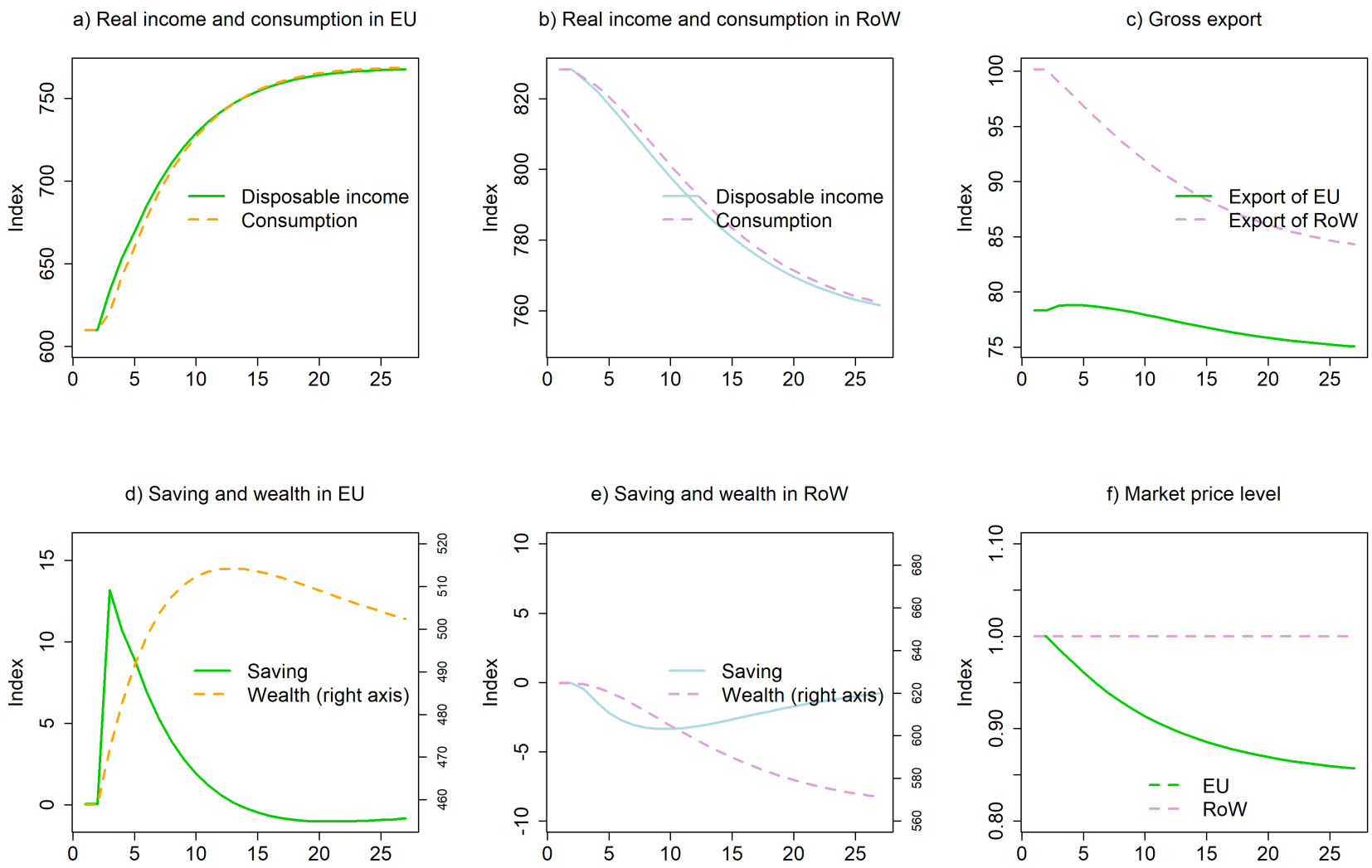
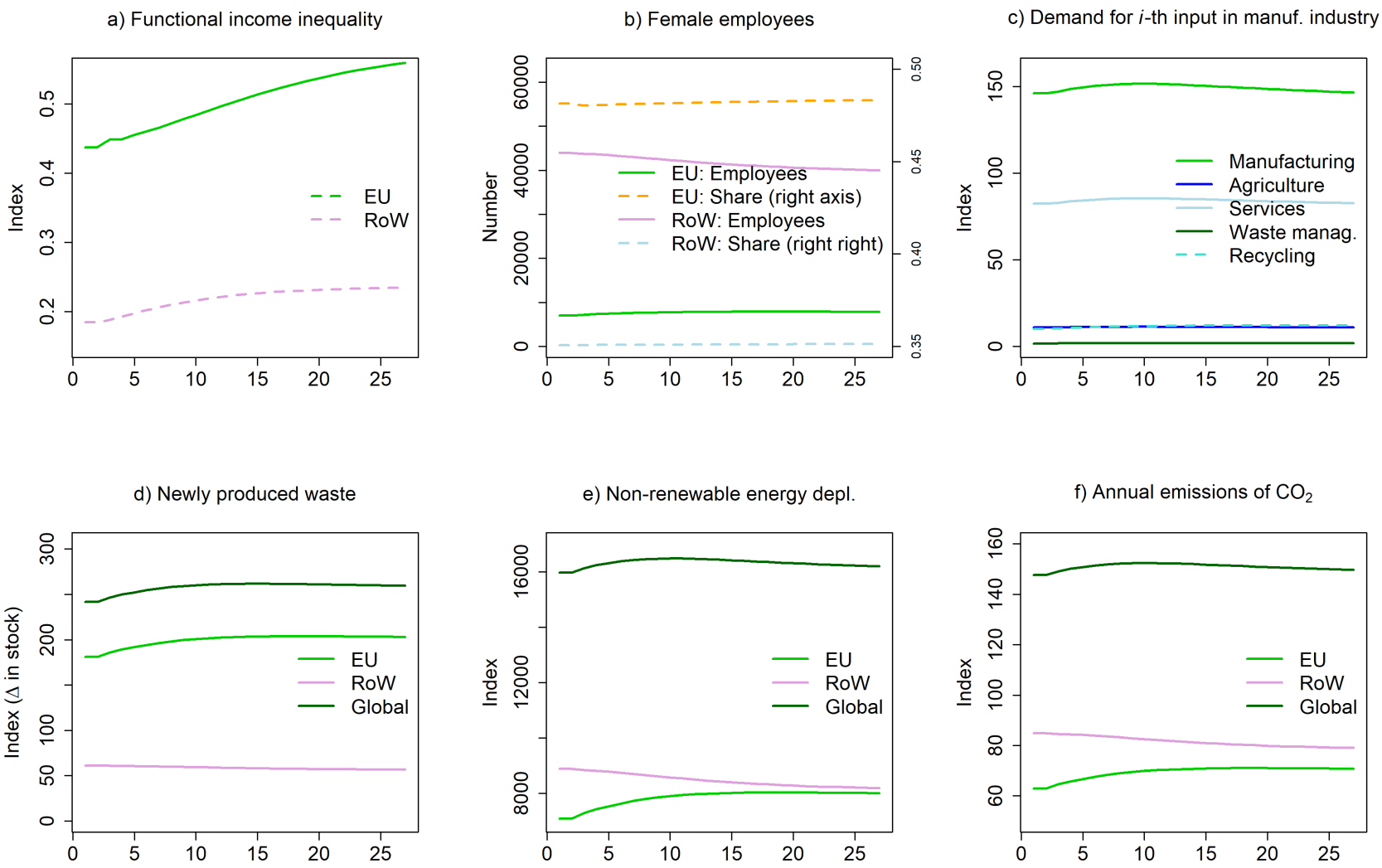


Figure 7. CE-oriented gov. spending in EU (cont'd)



Final remarks

- The model provides a benchmark for other MA-IO-SFC models

Final remarks

- The model provides a benchmark for other MA-IO-SFC models
- Next steps:

Final remarks

- The model provides a benchmark for other MA-IO-SFC models
- Next steps:
  a) Introduce landfill limit and consumption constraints

Final remarks

- The model provides a benchmark for other MA-IO-SFC models
- Next steps:
  a) Introduce landfill limit and consumption constraints
  b) Make additional experiments

Final remarks

- The model provides a benchmark for other MA-IO-SFC models
- Next steps:
  a) Introduce landfill limit and consumption constraints
  b) Make additional experiments
  c) Complete calibration with real data (*Exiobase*) / estimate coefficients

Final remarks

- The model provides a benchmark for other MA-IO-SFC models
- Next steps:
  a) Introduce landfill limit and consumption constraints
  b) Make additional experiments
  c) Complete calibration with real data (*Exiobase*) / estimate coefficients
  d) Turn into *n*-area model

Thank you

Download this presentation from:
https://www.marcopassarella.it/en/circular-economy-innovations-4/