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

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  ◦ 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

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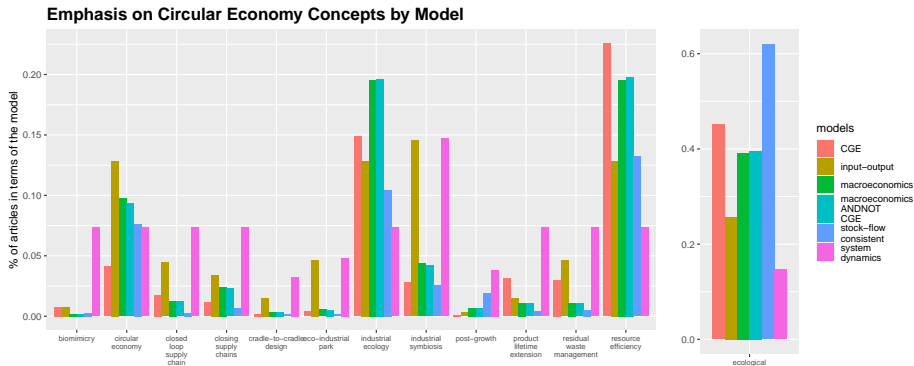# A SYSTEMATIC LITERATURE REVIEW

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– We have focused on both topics and modeling techniques

– We have identified, discussed, and assessed the most popular/promising tools (to model the transition...)

Emphasis on Circular Economy Concepts by Model

Source: Valles-Codina et al. (2022)

FIGURE A2. CITATION NETWORK OF FILTERED ENTRIES
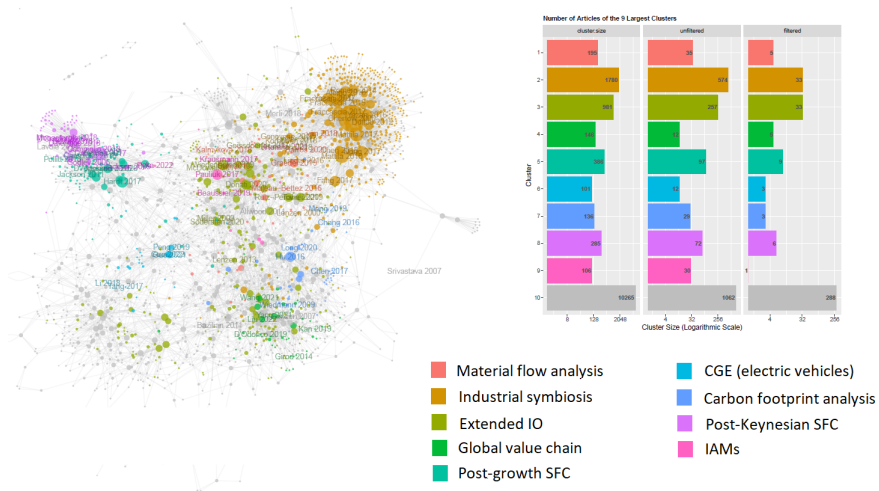
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– In principle, we can disaggregate SFC models by crossbreeding them with IO models... (Hardt and O'Neill 2017)

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  2) To assess the impact of a simple CE innovation on the economy, the society and the ecosystem

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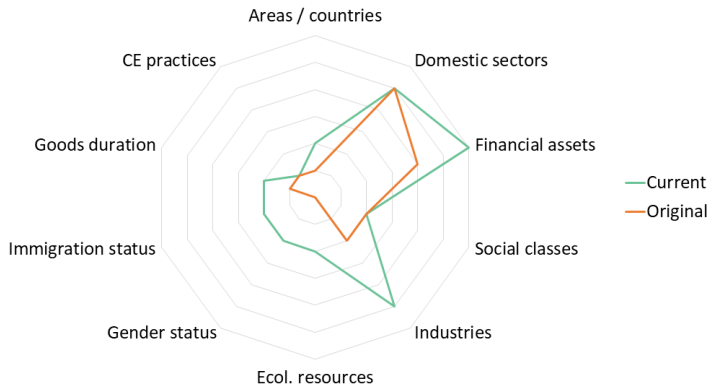
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d) Solution: numerical simulations (*R* code), 100 periods, 100 iterations

Figure 1. Model dimensions

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

	EU					xr	RoW					Tot
	H	F	G	B	CB		H	F	G	B	CB	
Money	83.13	0	0	0	-83.13	1	270.40	0	0	0	-270.4	0
Advances	0	0	0	0	0	1	0	0	0	0	0	0
Deposits	554.25	0	0	-554.25	0	1	2163.29	0	0	-2163.29	0	0
Loans	-110.50	-371.11	0	481.61	0	1	-424.54	-1658.9	0	2083.44	0	0
EU bills	87.81	0	-255.42	72.64	66.27	1	28.70	0	0	0	0	0
RoW bills	26.34	0	0	0	16.86	1	287.02	0	-680.47	79.85	270.4	0
EU shares	219.53	-248.23	0	0	0	1	28.70	0	0	0	0	0
RoW shares	17.56	0	0	0	0	1	516.64	-534.2	0	0	0	0
Capital stock	0	619.34	0	0	0	1	0	2193.1	0	0	0	2812.45
Net financial wealth	-878.13	0	255.42	0	0	1	-2870.21	0	680.47	0	0	-2812.45
Total	0	0	0	0	0		0	0	0	0	0	0

TRANSACTIONS AND Δ IN STOCKS

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

	EU						xr	RoW						Tot
	H	F (y)	F (k)	G	B	CB		H	F (y)	F (k)	G	B	CB	
Consumption	-831.32	831.32	0	0	0	0	1	-2703.96	2703.96	0	0	0	0	0
Investment	0	212.26	-154.84	-57.42	0	0	1	0	923.48	-657.93	-265.55	0	0	0
Government spending	0	269.91	0	-269.91	0	0	1	0	766.98	0	-766.98	0	0	0
Export of EU	0	217.08	0	0	0	0	1	0	-217.08	0	0	0	0	0
Import of EU	0	-213	0	0	0	0	1	0	213	0	0	0	0	0
[Value added]	0	[1195.75]	0	0	0	0	1	0	[4018.28]	0	0	0	0	0
Wage bill	614.74	-614.74	0	0	0	0	1	1976.22	-1976.22	0	0	0	0	0
Corporate profit	414.20	-418.75	0	0	0	0	1	1338.91	-1334.36	0	0	0	0	0
Amortization	0	-154.84	154.84	0	0	0	1	0	-657.93	657.93	0	0	0	0
Bank profit	4.81	0	0	0	-4.81	0	1	42.45	0	0	0	-42.45	0	0
CB profit	0	0	0	1.00	0	-1.00	1	0	0	0	5.41	0	-5.41	0
Income tax revenue	-207.18	0	0	207.18	0	0	1	-668.56	0	0	668.56	0	0	0
VAT revenue	0	-102.09	0	102.09	0	0	1	0	-352.69	0	352.69	0	0	0
Tariffs revenue	0	-19.73	0	19.36	0	0	1	0	-19.36	0	19.73	0	0	0
Interests on deposits	5.54	0	0	0	-5.54	0	1	21.62	0	0	0	-21.62	0	0
Interests on loans	-2.20	-7.42	0	0	9.63	0	1	-12.71	-49.77	0	0	62.48	0	0
Interests on EU bills	0.88	0	0	-2.55	0.73	0.66	1	0.29	0	0	0	0	0	0
Interests on RoW bills	0.53	0	0	0	0	0.34	1	5.74	0	0	-13.61	1.60	5.41	0
Change in money stock	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Change in advances	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Change in deposits	-0.31	0	0	0	0.31	0	1	-0.94	0	0	0	0.94	0	0
Change in loans	0.31	0	0	0	-0.31	0	1	0.94	0	0	0	-0.94	0	0
Change in EU bills	0	0	0	0.25	0	-0.25	1	0	0	0	0	0	0	0
Change in RoW bills	0	0	0	0	0	0.25	1	0	0	0	-0.25	0	0	0
Change in EU shares	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Change in RoW shares	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Revaluation effects							1							0
Total	0	0	0	0	0	0		0	0	0	0	0	0	0

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

	A in EU	M in EU	S in EU	W in EU	R in EU	A in RoW	M in RoW	S in RoW	W in RoW	R in RoW	Final demand	Output
Agriculture in EU	5.03	22.86	2.43	0.01	0.05	0.24	1.03	0.45	0.01	0	28.04	60.14
Manufacturing in EU	11.38	305.85	98.08	1.22	7.42	1.65	45.32	16.6	0.14	0.29	480.15	968.11
Services in EU	8.63	167.66	387.89	2.36	6.28	0.76	13.59	28.67	0.16	0.1	891.13	1507.23
Waste manag. in EU	0.25	3.56	4.17	1.28	0.37	0.07	0.23	0.21	0.01	0	0	10.16
Recycling in EU	0.13	18	1.92	0.09	1.91	0.01	2.48	0.22	0	0.04	0	24.78
Agriculture in RoW	0.98	2.71	0.67	0	0.03	49.5	156.01	26.02	0.21	0.12	169.45	3934
Manufacturing in RoW	1.96	75.84	14.96	0.14	2.62	51.04	1761.35	455.15	5.33	5.22	1560.39	405.69
Services in RoW	0.39	12.49	31.17	0.15	0.4	54.46	577	1244.55	7.22	3.54	2826.04	4757.39
Waste manag. in RoW	0.02	0.22	0.09	0.02	0.01	2.84	11.88	20.57	2.05	0.1	0	37.8
Recycling in RoW	0	0.29	0.02	0	0.02	0.87	11.67	0.49	0.02	1.1	0	14.48
Value added												
– Compensation of employees	5.73	163.52	462.92	1.9	4.05	111.89	507.12	1433.5	11.09	2.84		2704.57
– G.O. surplus and mixed inc.s	25.63	195.13	502.9	2.99	1.61	132.37	846.32	1530.98	11.55	1.14		3250.63
Taxes on production	0	0	0	0	0	0	0	0	0	0		
Output	60.14	968.11	1507.23	10.16	24.78	405.69	3934	4757.39	37.8	14.48	5955.19	

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:

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

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- Households' total disposable income in each area is:

$$\begin{aligned}
YD^z = WB^z + DIV^z + FB^z + \\
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+ \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
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- Households' net wealth is:

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

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

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

(4)

Selected equations: firms (current)

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

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

- The gross output vector is:

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

SELECTED EQUATIONS: FIRMS (CURRENT)

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

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

(4)

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(5)

- The value added in each area is:

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

(6)

SELECTED EQUATIONS: CONSUMER CHOICES

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

$$\beta_1^z = \bar{\beta}_1^z \qquad (7)$$

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

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- 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:

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

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The real gross investment is:

$$i^z_d = \gamma^z \cdot \left(k^{z*} - k^z_{-1} \right) + \delta^z \cdot k^z_{-1} \tag{11}$$

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The real gross investment is:

$$i^z_d = \gamma^z \cdot (k^{z*} - k^z_{-1}) + \delta^z \cdot k^z_{-1} \tag{11}$$

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

$$L^z_F = L^z_{F,-1} + i^z_d \cdot p^z_I - AF^z - FF^z_u - \Delta E^z_s \tag{12}$$

where:

$$AF^z = \delta^z \cdot k^z_{-1} \cdot p^z_I - k^z \cdot \Delta p^z_I$$

- 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:

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

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- The supply of bank deposits is:

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

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

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

SELECTED EQUATIONS: LABOUR MARKET AND POPUL.

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

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

- The available labour force in each area is:

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

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- Immigration inflow in each area is:

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

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

$$\rho_j^z = \rho_{0j}^z - \rho_{1j}^z \cdot (w_j^z - w_{j,-1}^z) \qquad (19)$$

- The government budget deficit in each area is:

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

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- Therefore, the supply of government bills is:

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

SELECTED EQUATIONS: GOVERNMENT AND CB

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

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- Cash supply adjusts to households' demand:

$$H_s^z = H_h^z \qquad (23)$$

Selected equations: prices

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

$$\mathbf{p}^{z*} = \mathbf{w}^z \odot \mathbf{l}^z + \mathbf{p}^{z*} \cdot \mathbf{A} \odot \mathbf{m}^{z*} \odot \mathbf{h}_d^z \qquad (24)$$

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

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

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

$$p_A^z = \mathbf{p}^{zT} \cdot \beta^z \tag{26}$$

SELECTED EQUATIONS: PORTFOLIO CHOICES

- Households' demand for domestic bills is:

$$\frac{B_{h,z}^z}{V^z} = \lambda_{10} + \lambda_{11} \cdot r_{b,-1}^z - \lambda_{12} \cdot \left(r_{b,-1}^f + \frac{\Delta xr^f}{xr^f} \right) - \lambda_{13} \cdot r_{m,-1}^z - \lambda_{14} \cdot \frac{YD^z}{V^z} +$$

$$- \lambda_{15} \cdot r_{e,-1}^z - \lambda_{16} \cdot \left(r_{e,-1}^f + \frac{\Delta xr^f}{xr^f} \right)$$

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- Households' demand for cash is:

$$H_h^z = \lambda_c^z \cdot c_{-1}^z \cdot p_{A,-1}^z$$

(28)

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$$H_h^z = \lambda_c^z \cdot c_{-1}^z \cdot p_{A,-1}^z$$

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- Bank deposits are the buffer stock:

$$M_h^z = V^z + L_h^z - H_h^z - B_{h,z}^z - B_{h,z}^f - E_{h,z}^z - E_{h,z}^f$$

(29)

Selected equations: portfolio choices

- Households' demand for domestic bills is:

$$\frac{B_{h,z}^z}{V^z} = \lambda_{10} + \lambda_{11} \cdot r_{b,-1}^z - \lambda_{12} \cdot \left(r_{b,-1}^f + \frac{\Delta xr^f}{xr^f} \right) - \lambda_{13} \cdot r_{m,-1}^z - \lambda_{14} \cdot \frac{YD^z}{V^z} +$$
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(29)

- The redundant equation is:

$$B_{cb,z}^z = B_s^z - B_{s,z}^z - B_{s,f}^z - B_b^z$$

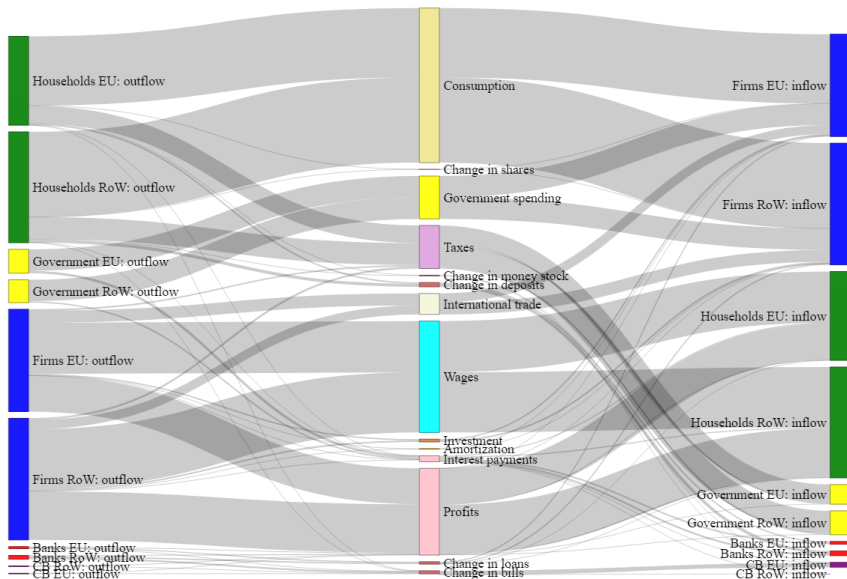FIGURE 2. SANKEY DIAGRAM OF TRANSACTIONS (IN $t = 20$)

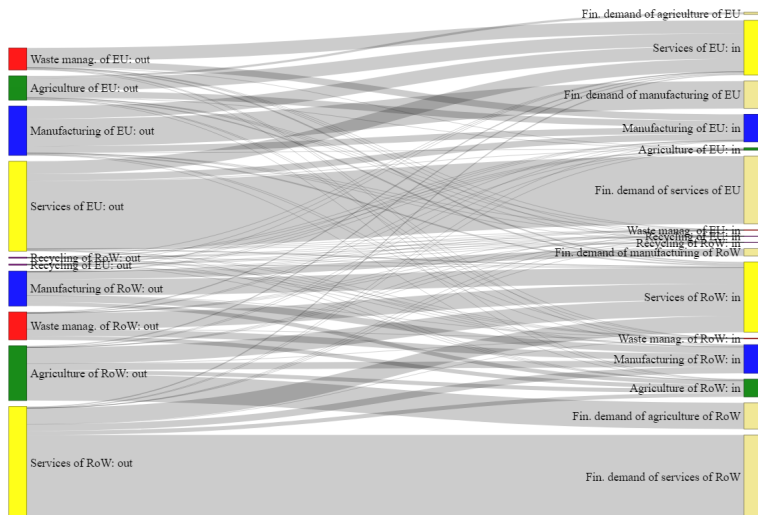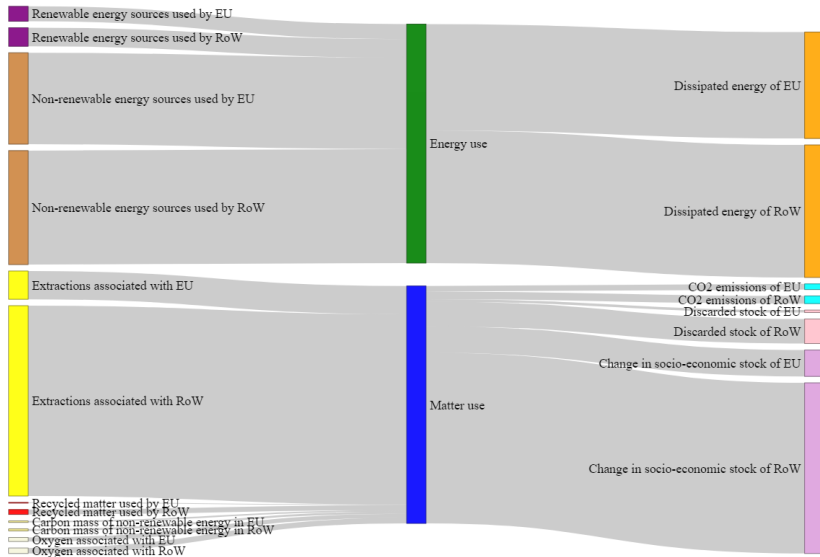FIGURE 3. CROSS-INDUSTRY INPUT-OUTPUT FLOWS (IN $t = 20$)

FIGURE 4. PHYSICAL FLOWS OF MATTER AND ENERGY (IN $t = 20$)

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

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- 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)

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

- The new matrix will be:

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

A simple CE innovation in EU

- The new matrix will be:

$$\mathbf{A'} = \left(\begin{array}{ccccc||ccccc}
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a'_{21} \leq a_{21} & a'_{22} \leq a_{22} & a'_{23} \leq a_{23} & a'_{24} \leq a'_{24} & a'_{25} > 0 & a_{26} & a_{27} & a_{28} & a_{29} & 0 \\
a'_{31} \leq a_{31} & a'_{32} \leq a_{32} & a'_{33} \leq a_{33} & a'_{34} \leq a'_{34} & a'_{35} > 0 & a_{36} & a_{37} & a_{38} & a_{39} & 0 \\
a'_{41} \leq a_{41} & a'_{42} \leq a_{42} & a'_{43} \leq a_{43} & a'_{44} \leq a'_{44} & a'_{45} > 0 & a_{46} & a_{47} & a_{48} & a_{49} & 0 \\
a'_{51} > 0 & a'_{52} > 0 & a'_{53} > 0 & a'_{54} > 0 & 0 & a_{56} & a_{57} & a_{58} & a_{59} & 0 \\
\hline
a'_{61} \leq a_{61} & a'_{62} \leq a_{62} & a'_{63} \leq a_{63} & a'_{64} \leq a'_{64} & a'_{65} > 0 & a_{66} & a_{67} & a_{68} & a_{69} & 0 \\
a'_{71} \leq a_{71} & a'_{72} \leq a_{72} & a'_{73} \leq a_{73} & a'_{74} \leq a'_{74} & a'_{75} > 0 & a_{76} & a_{77} & a_{78} & a_{79} & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array} \right)$$

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

- The new matrix will be:

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

- 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:

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

The role of the government sector

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

where γ_A is defined as:

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

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- The average speed of convergence of technical coefficients to their target values is a linear, positive function of industry-specific government expenditures
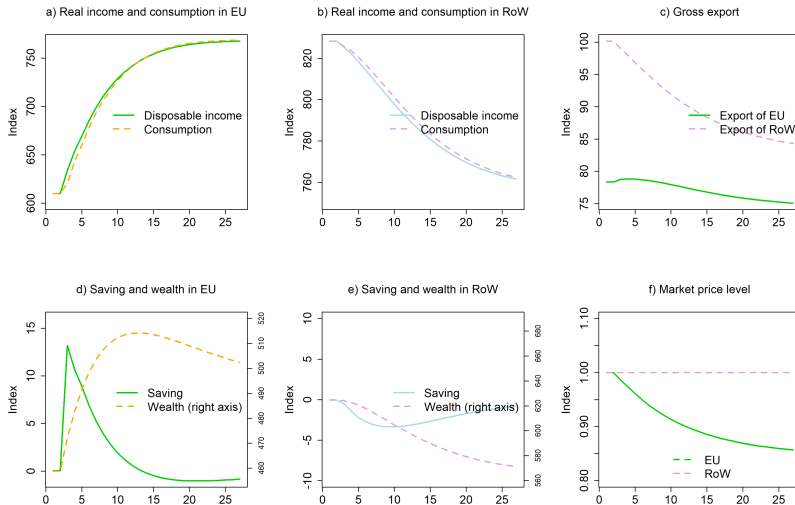
FIGURE 5. CE-ORIENTED GOV. SPENDING IN EU

a) Real income and consumption in EU

b) Real income and consumption in RoW

c) Gross export

d) Saving and wealth in EU

e) Saving and wealth in RoW

f) Market price level

FIGURE 6. CE-ORIENTED GOV. SPENDING IN EU (CONT'D)

a) Functional income inequality

b) Female employees

c) Demand for i-th input in manuf. industry

d) Newly produced waste

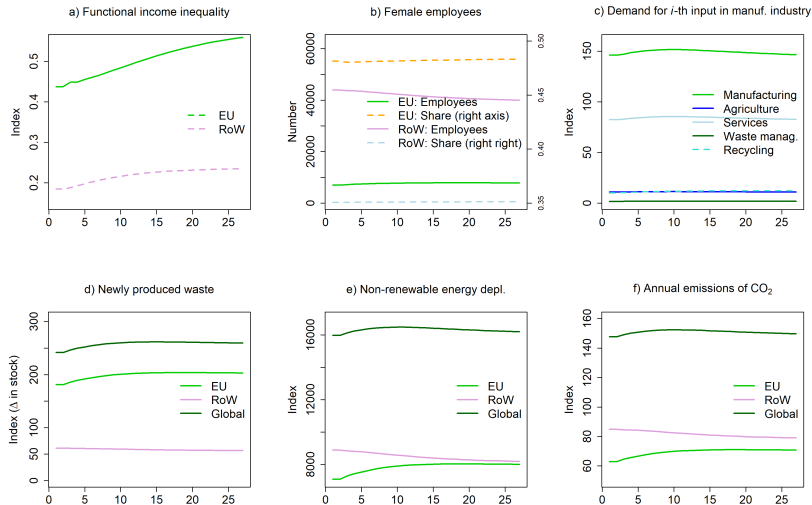e) Non-renewable energy depl.

f) Annual emissions of CO_2

FIGURE 7. HIGHER RECYCLING RATE IN EU

Shock 4: Higher Recycling Rate
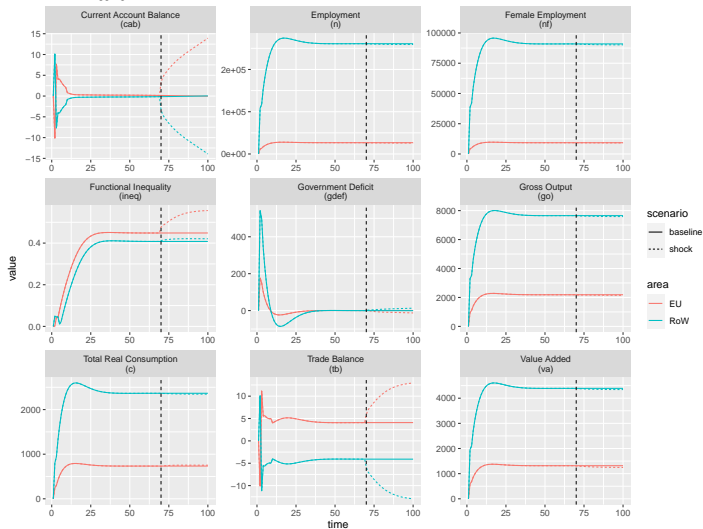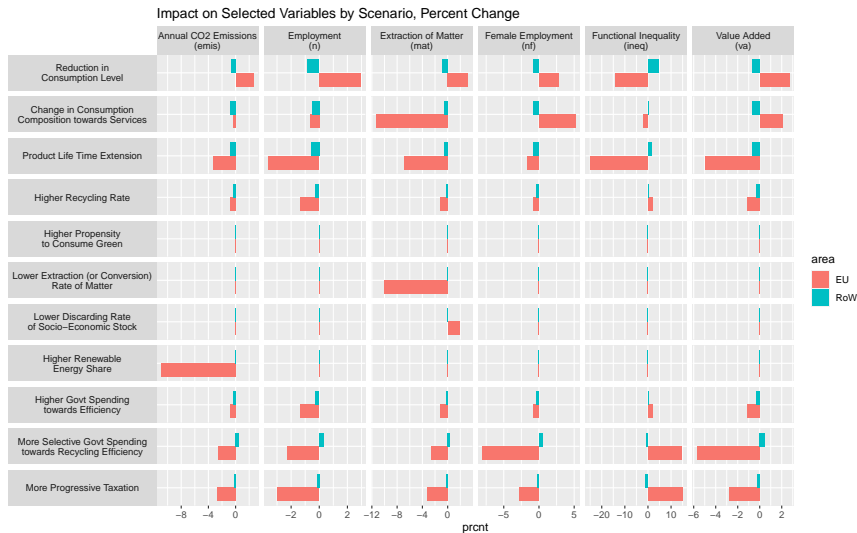Selected Aggregate Macroeconomic Indicators. Vertical dashed line indicates shock time

FIGURE 8. HIGHER RECYCLING RATE IN EU (CONT'D)

Impact on Selected Variables by Scenario, Percent Change

Final remarks

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

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- What are we doing next?:

FINAL REMARKS

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    a) Make additional experiments

FINAL REMARKS

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Final remarks

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

- What are we doing next?:

    a) Make additional experiments

    b) Introduce other features

    c) Explore other word-economy partitions

Thank you

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