Circular economy innovations in an input-output stock-flow consistent dynamic model

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JUST2CE

A Just Transition to Circular Economy

Download slides and code from MARXIANOMICS:

https://www.marcopassarella.it/en/

RESEARCH QUESTIONS

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

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d) Identification: reasonable values / neutrality

e) Solution: numerical simulation (R code)

Nominal value of assets and liabilities

Table 1: Balance sheet in period $t = 20$ (baseline scenario)

	Households	Firms	Government	Banks	CB	Foreign	Total
Money	46.43	0	0	0	-46.43	0	0
Advances	0	0	0	0	0	0	0
Deposits	272.29	0	0	-272.29	0	0	0
Loans	0	-36.62	0	36.62	0	0	0
Bills	35.41	0	-367.09	235.67	46.43	49.58	0
Capital stock	0	36.62	0	0	0	0	36.62
Net financial wealth	-354.13	0	367.09	0	0	-49.58	-36.62
Total	0	0	0	0	0	0	0

TABLE 2: Transactions-flow matrix in period $t = 20$ (baseline scenario)

	Households	Firms		Government	Banks	CB	Foreign	Tot.
		Current	Capital					
Consumption	-522.91	522.91	0	0	0	0	0	0
Investment	0	11.55	-11.55	0	0	0	0	0
Government spending	0	180	0	-180	0	0	0	0
Export	0	73.29	0	0	0	0	-73.29	0
Import	0	-78.77	0	0	0	0	78.77	0
[Value added]	0	[708.97]	0	0	0	0	0	0
Wage bill	322.26	-322.26	0	0	0	0	0	0
Corporate profit	383.80	-383.8	0	0	0	0	0	0
Amortization	0	-1.83	1.83	0	0	0	0	0
Bank profit	4.67	0	0	0	-4.67	0	0	0
Tax revenue	-142.97	0	0	142.97	0	0	0	0
Interests on deposits	4.67	0	0	0	-4.67	0	0	0
Interests on loans	0	-1.08	0	0	1.08	0	0	0
Interests on bills	1.21	0	0	-11.18	8.27	0	1.70	0
Change in money stock	-6.93	0	0	0	0	6.93	0	0
Change in advances	0	0	0	0	0	0	0	0
Change in deposits	-38.73	0	0	0	38.73	0	0	0
Change in loans	0	0	9.71	0	-9.71	0	0	0
Change in bills	-5.07	0	0	48.20	-29.02	-6.93	-7.18	0
Total	0	0	0	0	0	0	0	0

- Total "real" consumption is:

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

SELECTED EQUATIONS: HOUSEHOLDS

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- Households' total disposable income:

$$YD = w \cdot N + F_f + F_b + r_{m,-1} \cdot M_{h,-1} + r_{b,-1} \cdot B_{h,-1} - T \quad (2)$$

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- Disposable labour income in each industry j is:

$$YD_j^w = w \cdot N_j \cdot (1 - \theta), \quad with : j = 1, 2 \qquad (3)$$

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- Let us consider a 3×3 production. The final demand vector is:

$$\mathbf{d} = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{pmatrix} \cdot c + \begin{pmatrix} \iota_1 \\ \iota_2 \\ \iota_3 \end{pmatrix} \cdot i_d + \begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \end{pmatrix} \cdot gov + \begin{pmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{pmatrix} \cdot exp \quad (4)$$

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- The gross output vector is:

$$\mathbf{x} = \mathbf{A} \cdot \mathbf{x} + \mathbf{d} = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{d}, \ with : \mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \quad (5)$$

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- The net domestic income of home country is:

$$Y_n = \mathbf{p}^T \cdot \mathbf{d} - \mathbf{p}^T \cdot (\mathbf{m} \odot \mathbf{d}) \quad (6)$$

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

$$k^* = \frac{\mathbf{p}_{-1}^T \cdot (\mathbf{h} \odot \mathbf{x}_{-1})}{p_{I,-1}} \tag{7}$$

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The real gross investment is:

$$i_d = \gamma \cdot (k^* - k_{-1}) + \delta \cdot k \qquad (8)$$

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SELECTED EQUATIONS: FIRMS (CAPITAL)

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The real gross investment is:

$$i_d = \gamma \cdot (k^* - k_{-1}) + \delta \cdot k \tag{8}$$

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

$$L_f = L_{f,-1} + i_d \cdot p_1 - AF, \quad with: AF = \delta \cdot k \cdot p_1 \tag{9}$$

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- The supply of bank loans is:

$$L_s = L_{s,-1} + \Delta L_f \qquad (10)$$

SELECTED EQUATIONS: COMMERCIAL BANKS

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- The supply of bank deposits is:

$$M_s = M_h \tag{11}$$

Selected equations: commercial banks

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- Bank holdings of government bills are:

$$\textit{if } M_s \geq L_s \textit{ then } B_b = M_s - L_s \textit{ else } B_b = 0 \qquad (12)$$

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- whereas advances obtained from the CB are:

$$\text{if } M_s < L_s \text{ then } A_d = L_s - M_s \text{ else } A_d = 0 \qquad (13)$$

- The supply of government bills is:

$$B_s = B_{s,-1} + g \cdot p_G - T + r_b \cdot (B_h + B_b + B_{fo}) \qquad (14)$$

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- At the end of each period, the central bank holds the residual amount of bills:

$$B_{cb} = B_s - B_h - B_b - B_f o \qquad (15)$$

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- Therefore, cash supply is:

$$H_s = H_{s,-1} + (B_{cb} - B_{cb,-1}) + (A_s - A_{s,-1}) \qquad (16)$$

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- Real export follows a stock-flow norm:

$$exp = \alpha_4 \cdot \frac{YD_{fo}}{E(p_{fo})} + \alpha_5 \cdot \frac{V_{fo,-1}}{p_{fo,-1}} \qquad (17)$$

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SELECTED EQUATIONS: FOREIGN MARKET

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- The final demand for imported goods and services is:

$$\mathbf{imp} = \mathbf{m} \odot \mathbf{d} \tag{18}$$

Selected equations: foreign market

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- The final demand for imported goods and services is:

$$\mathbf{imp} = \mathbf{m} \odot \mathbf{d} \qquad (18)$$

- The foreign stock of net wealth is:

$$V_{fo} = V_{fo,-1} + YD_{fo} - p_{fo} \cdot exp \qquad (19)$$

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SELECTED EQUATIONS: PRICES

- If firms use a mark-up rule, the unit price of production vector is:

$$\mathbf{p}^* = w \cdot \mathbf{l} + \mathbf{p}^* \cdot \mathbf{A} \odot \mathbf{m}^* \tag{20}$$

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- If firms use a mark-up rule, the unit price of production vector is:

$$\mathbf{p}^* = w \cdot \mathbf{l} + \mathbf{p}^* \cdot \mathbf{A} \odot \mathbf{m}^* \qquad (20)$$

- However, actual prices only adjust gradually:

$$\mathbf{p} = \Gamma \odot \mathbf{p}_{-1} + \left[\begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \Gamma \right] \odot \mathbf{p}^* \qquad (21)$$

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- The average price of consumption is:

$$p_A = \mathbf{p}^T \cdot \beta, \quad with : \beta = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{pmatrix} \qquad (22)$$

- Households' demand for bills is:

$$\frac{B_h}{V} = \lambda_0 - \lambda_1 \cdot r_m + \lambda_2 \cdot r_b - \lambda_3 \cdot \frac{YD}{V} \tag{23}$$

SELECTED EQUATIONS: PORTFOLIO CHOICES

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- Households' demand for cash is:

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- Households' holdings of bank deposits are:

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- The redundant equation is:

$$H_h = H_s$$

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FIGURE 1. SANKEY DIAGRAM OF TFM (IN $t = 20$)

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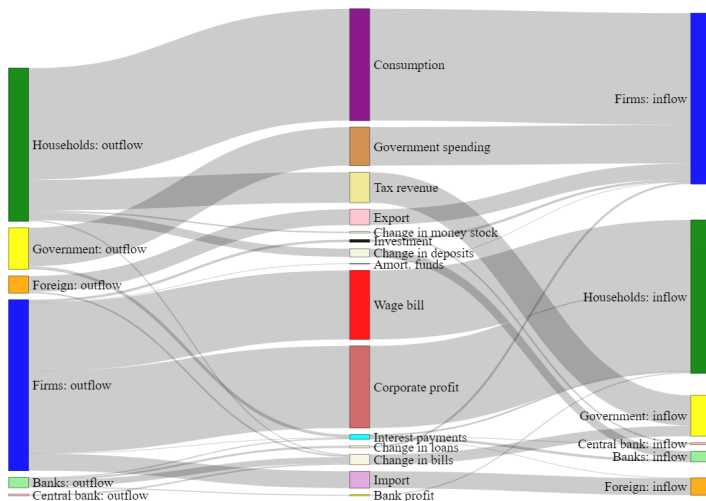
FIGURE 2. CROSS-INDUSTRY PHYSICAL FLOWS (IN $t = 205$)
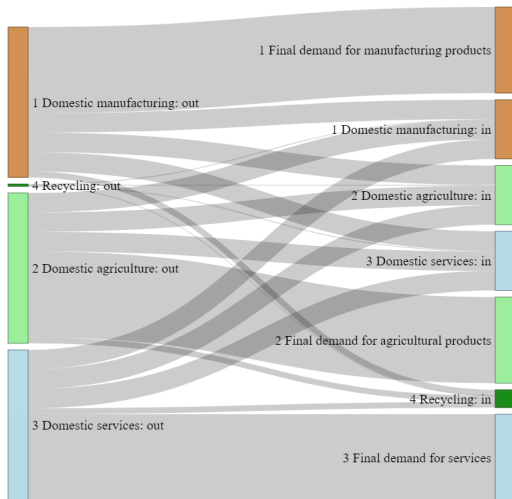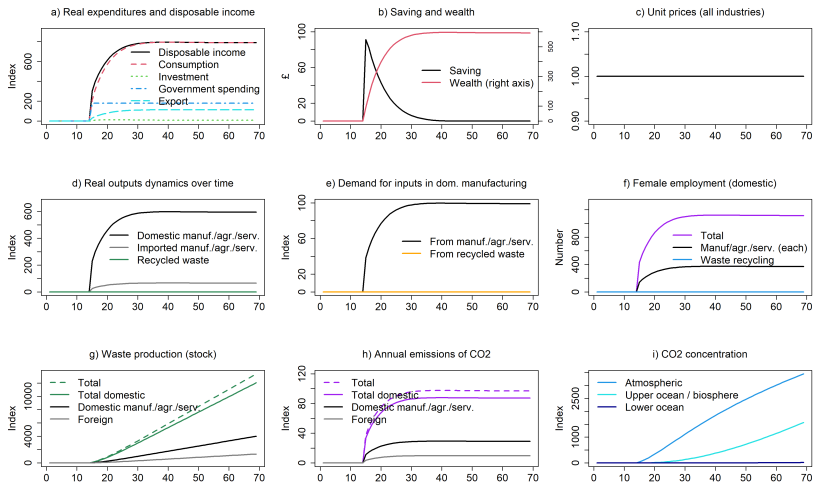
FIGURE 3. MODEL DYNAMICS: BASELINE

Input-output table

TABLE 3: Input-output matrix in period $t = 20$ (baseline scenario)

	Manuf.	Agric.	Serv.	Recyc.	Total	Fin. dem.	Tot. output
Manufacturing (production)	67.67	67.67	67.67	0	203.02	248.14	451.16
Agriculture (production)	67.67	67.67	67.67	0	203.02	248.14	451.16
Services (provision)	67.67	67.67	67.67	0	203.02	248.14	451.16
Recycling (production)	0	0	0	0	0	0	0
Value added	236.32	236.32	236.32	0	708.97		
~ Disposable income	191.22	191.22	191.22	0	573.65		
~ Tax revenue	47.66	47.66	47.66	0	142.97		
~ Interest payments (-)	-2.55	-2.55	-2.55	0	-7.65		
Import (production)	11.82	11.82	11.82	0	35.45	-35.45	
Total output	451.16	451.16	451.16	0	1353.49	708.97	1353.49

EXTENDED INPUT-OUTPUT TABLE

TABLE 4: Extended IO matrix in period $t = 20$ (baseline scenario)

	Manufacturing	Agriculture	Services	Recycling	Total
Disposable labour income	85.94	85.94	85.94	0	257.81
Disposable capital income	105.28	105.28	105.28	0	315.84
Functional income inequality	0.18	0.18	0.18	0	0.18
Total employment	537.10	537.10	537.10	0	1611.30
~ Male employment	268.55	268.55	268.55	0	805.65
~ Female employment	268.55	268.55	268.55	0	805.65
Share of female employment	0.50	0.50	0.50	0	0.50
Waste production	220.97	220.97	220.97	0	662.91
Annual emissions of CO_2	21.05	21.05	21.05	0	63.16

The circular economy (CE)

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THE CIRCULAR ECONOMY (CE)

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- Consider a 4-industry economy: 3 goods + waste. If waste is not recycled, the matrix of technical coefficients is:

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

THE CIRCULAR ECONOMY (CE)

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

A simple CE innovation

- The new matrix will be:

$$\mathbf{A'} = \begin{pmatrix} a'_{11} \leq a_{11} & a'_{12} \leq a_{12} & a'_{13} \leq a_{13} & a'_{14} \geq 0 \\ a'_{21} \leq a_{21} & a'_{22} \leq a_{22} & a'_{23} \leq a_{23} & a'_{24} \geq 0 \\ a'_{31} \leq a_{31} & a'_{32} \leq a_{32} & a'_{33} \leq a_{33} & a'_{34} \geq 0 \\ a'_{41} \geq 0 & a'_{42} \geq 0 & a'_{43} \geq 0 & 0 \end{pmatrix}$$

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- Fall in coefficients defining the quantities of manuf. and agric. products and services used as inputs ($\bullet$)

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- Fall in coefficients defining the quantities of manuf. and agric. products and services used as inputs (•)

- Waste now enters the production process (•)

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A simple CE innovation

- The new matrix will be:

$$\mathbf{A'} = \begin{pmatrix} a'_{11} \leq a_{11} & a'_{12} \leq a_{12} & a'_{13} \leq a_{13} & a'_{14} \geq 0 \\ a'_{21} \leq a_{21} & a'_{22} \leq a_{22} & a'_{23} \leq a_{23} & a'_{24} \geq 0 \\ a'_{31} \leq a_{31} & a'_{32} \leq a_{32} & a'_{33} \leq a_{33} & a'_{34} \geq 0 \\ a'_{41} \geq 0 & a'_{42} \geq 0 & a'_{43} \geq 0 & 0 \end{pmatrix}$$

- Fall in coefficients defining the quantities of manuf. and agric. products and services used as inputs ($\bullet$)

- Waste now enters the production process ($\bullet$)

- Manuf. and agric. products and services are used as inputs in waste industry ($\bullet$)

THE ROLE OF THE GOVERNMENT SECTOR

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

$$a_{ij} = a_{ij,-1} + \gamma_A \cdot \left(a'_{ij,-1} - a_{ij,-1} \right) \tag{26}$$

The role of the government sector

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- where γ_A is defined as:

$$\gamma_A = \gamma_A^0 + \Gamma_A^T \cdot \sigma \cdot gov_{-1} \qquad (27)$$

WASTE AND EMISSIONS

- The quantity of waste generated by each (domestic) industry is:

$$WA_j = WA_{j,-1} + (x_j - x_{j,fo}) \cdot (\zeta_j - a_{j,4}) \qquad (28)$$

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- Atmospheric CO_2 concentration is then calculated using carbon cycle equations.

FIGURE 4. SELECTED VARIABLES AFTER CE INNOVATION

a) Real expenditures and disposable income
b) Saving and wealth
c) Unit prices
d) Real outputs dynamics over time
e) Demand for inputs in manufacturing industry
f) Female employment (domestic)
g) Waste production (stock)
h) Annual emissions of CO2
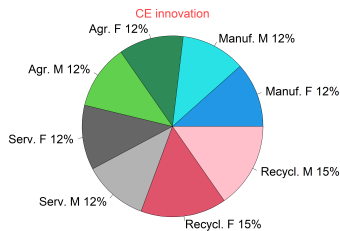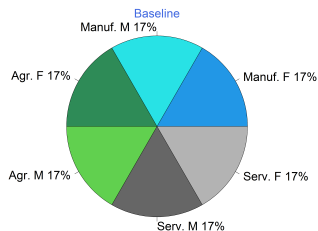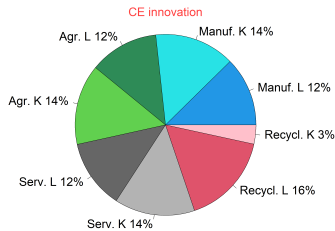i) CO2 concentration
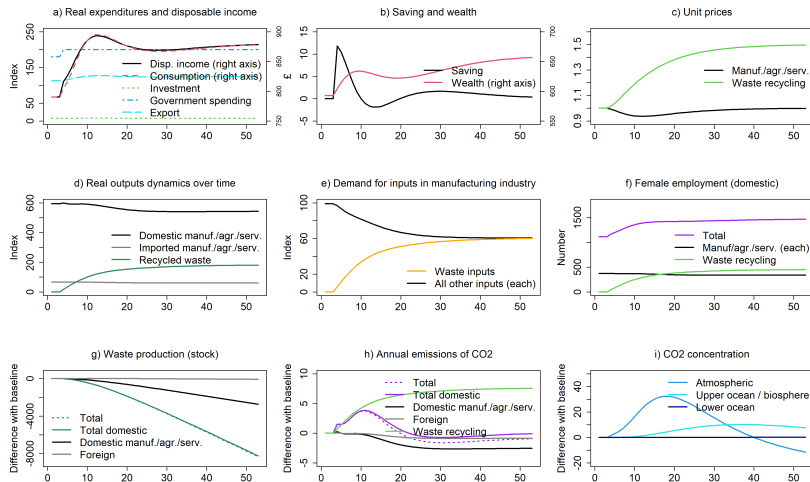
FIGURE 5. INCOME DISTRIBUTION AND GENDER SEGREGATION
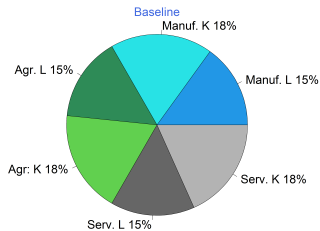
FIGURE 6. GENDER SEGREGATION OVER TIME
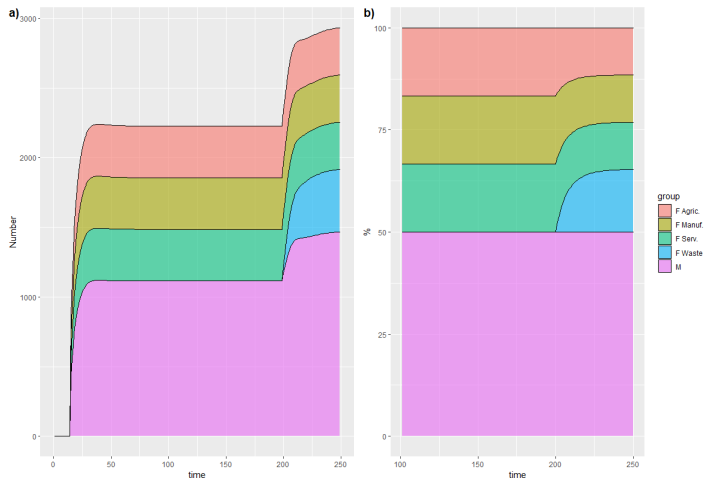
FIGURE 7. THE FOREIGN SECTOR

b) CAB and TB

B) Export and import

c) Foreign disposable income

d) CAB components

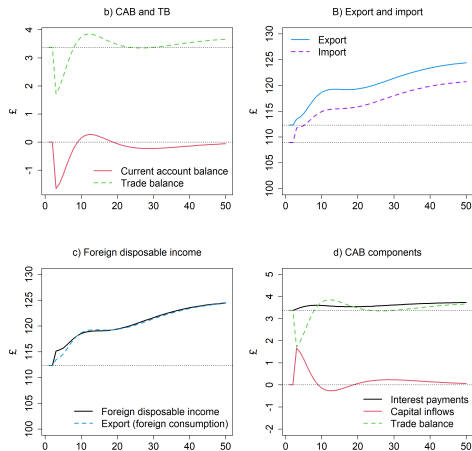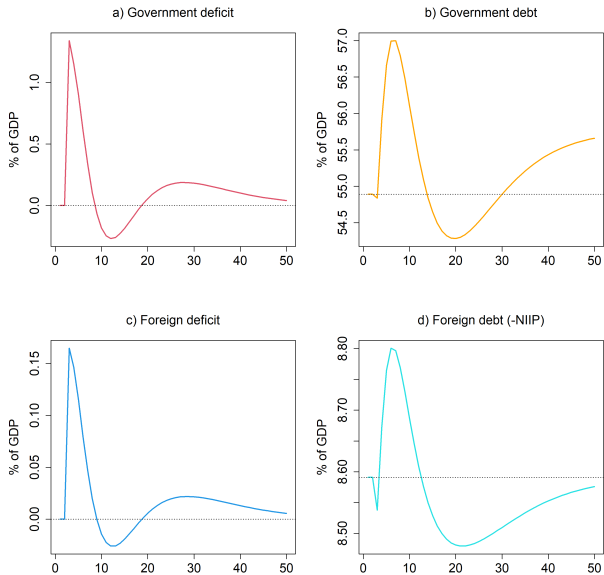FIGURE 8. PUBLIC FINANCES

a) Government deficit

b) Government debt

c) Foreign deficit

d) Foreign debt (-NIIP)

FINAL REMARKS

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Final remarks

- Simplified though it is, this model provides a benchmark for more sophisticated IO-SFC models

- Next steps:

    a) Improve investment function

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    b) Turn into 2- or 3-area model

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    d) Test on real data / estimate coefficients
    e) Improve CE experiments
    f) Improve solver / perform stability analysis

Thank you

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