Is Green Transition Painful?—An Endogenous Growth Perspective

Lorant Kaszab Tamas Szoke

Central Bank of Hungary

EEA-ESEM 2025

Outline

1. Motivation
   - The effects of carbon taxation on the economy
2. Model
3. Calibration
4. Results
   - The mechanism
   - Inflation from one-sector and two-sector models
   - Benchmark two-sector result
   - Size of the final tax rate
   - Exogenous growth (frontloaded or backloaded tax).
   - Endo. vs. Exo. growth (benchmark calibration)
   - Endo. vs. Exo. (higher inflation coefficient, 1.5)
   - Fiscal subsidy
5. Summary

Outline

Carbon taxation

- EU plans to raise the share of green energy by 20 pp. to 45 % by 2030.
- Green transition: taxing emissions (tax on the price of brown inputs) in the brown sector
- Green innovation: productive capacity improves
- The role of monetary policy

Carbon taxation

- EU plans to raise the share of green energy by 20 pp. to 45 % by 2030.
- Green transition: taxing emissions (tax on the price of brown inputs) in the brown sector
- Green innovation: productive capacity improves
- The role of monetary policy

Carbon taxation

- EU plans to raise the share of green energy by 20 pp. to 45 % by 2030.
- Green transition: taxing emissions (tax on the price of brown inputs) in the brown sector
- Green innovation: productive capacity improves
- The role of monetary policy

Carbon taxation

- EU plans to raise the share of green energy by 20 pp. to 45 % by 2030.
- Green transition: taxing emissions (tax on the price of brown inputs) in the brown sector
- Green innovation: productive capacity improves
- The role of monetary policy

Previous literature

- Only two endogenous growth (discrete time) papers with green transition and monetary policy: Fornaro et al. (2024), Boehl et al. (2024).
- Endogenous growth (continuous time) papers with asset pricing and without monetary policy: Hambel et al. (2024a, 2024b), Van den Bremer and Van der Ploeg (2021), etc.
- Endogenous growth (continuous time) papers without monetary policy: Hamaguchi (2021), Itaya (2008), Ricci (2007), etc.
- Exogenous growth with monetary policy: Airaudo et al. (2021), Carattini et al. (2023), Coenen et al. (2023), Del Negro et al. (2023), Diluiso et al. (2021), Giovanardi et al. (2024), Heutel (2012), Nakov and Thomas (2021) etc.

Previous literature

- Only two endogenous growth (discrete time) papers with green transition and monetary policy: Fornaro et al. (2024), Boehl et al. (2024).
- Endogenous growth (continuous time) papers with asset pricing and without monetary policy: Hambel et al. (2024a, 2024b), Van den Bremer and Van der Ploeg (2021), etc.
- Endogenous growth (continuous time) papers without monetary policy: Hamaguchi (2021), Itaya (2008), Ricci (2007), etc.
- Exogenous growth with monetary policy: Airaudo et al. (2021), Carattini et al. (2023), Coenen et al. (2023), Del Negro et al. (202 Diluiso et al. (2021), Giovanardi et al. (2024), Heutel (2012), Nakov and Thomas (2021) etc.

Previous literature

- Only two endogenous growth (discrete time) papers with green transition and monetary policy: Fornaro et al. (2024), Boehl et al. (2024).
- Endogenous growth (continuous time) papers with asset pricing and without monetary policy: Hambel et al. (2024a, 2024b), Van den Bremer and Van der Ploeg (2021), etc.
- Endogenous growth (continuous time) papers without monetary policy: Hamaguchi (2021), Itaya (2008), Ricci (2007), etc.
- Exogenous growth with monetary policy: Airaudo et al. (2021), Carattini et al. (2023), Coenen et al. (2023), Del Negro et al. (202[illegible] Diluiso et al. (2021), Giovanardi et al. (2024), Heutel (2012), Nakov and Thomas (2021) etc.

Previous literature

- Only two endogenous growth (discrete time) papers with green transition and monetary policy: Fornaro et al. (2024), Boehl et al. (2024).
- Endogenous growth (continuous time) papers with asset pricing and without monetary policy: Hambel et al. (2024a, 2024b), Van den Bremer and Van der Ploeg (2021), etc.
- Endogenous growth (continuous time) papers without monetary policy: Hamaguchi (2021), Itaya (2008), Ricci (2007), etc.
- Exogenous growth with monetary policy: Airaudo et al. (2021), Carattini et al. (2023), Coenen et al. (2023), Del Negro et al. (2023), Diluiso et al. (2021), Giovanardi et al. (2024), Heutel (2012), Nakov and Thomas (2021) etc.

Textbook endogenous growth model of Romer (1986)

- Final goods producer uses green and brown intermediary goods and labor:

$$Y_t = L_t^{1-\alpha}[X_{G,t} + X_{B,t}]$$

where $X_{s,t} = \int_0^1 A_{s,t,i}^{1-\alpha} x_{s,t,i}^{\alpha} di$ for $s = \{G, B\}$.

- Brown input is taxed and green input is untaxed (tax revenues are transferred back to HHs as lump-sum transfers):

$$\frac{P_{G,t}}{P_t} = \frac{1}{\alpha}, \; \frac{P_{B,t}}{P_t} = \frac{1}{\alpha}(1 + \tau_t).$$

- Intermediary invests to improve the quality of the good (endogenous growth):

$$A_{G,t+1} = A_{G,t} + \chi S_{G,t}^{\zeta} A_t^{1-\zeta}$$

Textbook endogenous growth model of Romer (1986)

- Final goods producer uses green and brown intermediary goods and labor:

$$Y_t = L_t^{1-\alpha}[X_{G,t} + X_{B,t}]$$

where $X_{s,t} = \int_0^1 A_{s,t,i}^{1-\alpha} x_{s,t,i}^{\alpha} di$ for $s = \{G, B\}$.

- Brown input is taxed and green input is untaxed (tax revenues are transferred back to HHs as lump-sum transfers):

$$\frac{P_{G,t}}{P_t} = \frac{1}{\alpha}, \quad \frac{P_{B,t}}{P_t} = \frac{1}{\alpha}(1+\tau_t).$$

- Intermediary invests to improve the quality of the good (endogenous growth):

$$A_{G,t+1} = A_{G,t} + \chi S_{G,t}^{\zeta} A_t^{1-\zeta}$$

Textbook endogenous growth model of Romer (1986)

- Final goods producer uses green and brown intermediary goods and labor:
$$Y_t = L_t^{1-\alpha}[X_{G,t} + X_{B,t}]$$
where $X_{s,t} = \int_0^1 A_{s,t,i}^{1-\alpha} x_{s,t,i}^{\alpha} di$ for $s = \{G, B\}$.
- Brown input is taxed and green input is untaxed (tax revenues are transferred back to HHs as lump-sum transfers):
$$\frac{P_{G,t}}{P_t} = \frac{1}{\alpha}, \quad \frac{P_{B,t}}{P_t} = \frac{1}{\alpha}(1+\tau_t).$$
- Intermediary invests to improve the quality of the good (endogenous growth):
$$A_{G,t+1} = A_{G,t} + \chi S_{G,t}^{\zeta} A_t^{1-\zeta}$$

Calibration

Param.	Description	Value	Target
β	time discount factor	0.99	nominal interest rate of 4%
α	share of intermediary goods	0.5	share of intermediary goods in data
χ	constant in innov. function	0.0286	innov. spending-to-GDP ratio of 2%
η	constant in discounting	0.075/4	annual corporate discount rate of 7.5%
ζ	curvature of innov.	0.12	to generate a growth rate of 2 %
ψ	el. of intert. subst. (EIS)	1.5	common choice in literature
ϕ_Π	response to inflation	1.00	following Fornaro and Wolf (2023)
ϕ_Y	response to output gap	0.5	in the ballpark of Fornaro and Wolf (2
ξ	resp. of wages to labour gap	0.19	following Gali and Gambetti (2020)
λ	persistence of inflation	0.7	following Gali and Gambetti (2020)

Outline

Intuition on the mechanism

- Green input decomposition: $x_{G,t} = x_{G,t}/x_{B,t} * x_{B,t} = (1+\tau_t)^{\alpha/(1-\alpha)+1}\alpha^{2/(1-\alpha)}L_t \uparrow$
- $Profit_{G,t} = markup * x_{G,t} \uparrow$; Labour: $x_{G,t} = \alpha^{2/(1-\alpha)}L_t \uparrow$
- Investment Euler: $INV_{G,t} = \left[\sum_{t=0}^{\infty}\prod_{j=1}^{t}\frac{1}{1+r_j+\eta}\left(Profit_{G,t}\right)\right]^{\zeta/(1-\zeta)} \uparrow$.
- Growth equation: $g_{G,t+1} \equiv A_{G,t+1}/A_{G,t} = 1+\chi INV_{G,t}^{\zeta} \uparrow$.
- If monetary policy not too restrictive then consumption also higher (combine bond Euler+int. rate rule).
- $Y_t \uparrow = C_t \uparrow + INV_{G,t} \uparrow + x_{G,t} \uparrow + x_{B,t} \downarrow\downarrow$.
- $GDP_t \uparrow = Y_t \uparrow - x_{B,t} \downarrow\downarrow - x_{G,t} \uparrow = C_t \uparrow + INV_{G,t} \uparrow$

Intuition on the mechanism

- Green input decomposition:
  $x_{G,t} = x_{G,t}/x_{B,t} * x_{B,t} = (1+\tau_t)^{\alpha/(1-\alpha)+1}\alpha^{2/(1-\alpha)}L_t \uparrow$
- $Profit_{G,t} = markup * x_{G,t} \uparrow$; Labour: $x_{G,t} = \alpha^{2/(1-\alpha)}L_t \uparrow$
- Investment Euler: $INV_{G,t} = \left[\sum_{t=0}^{\infty}\prod_{j=1}^{t}\frac{1}{1+r_j+\eta}\left(Profit_{G,t}\right)\right]^{\zeta/(1-\zeta)} \uparrow$.
- Growth equation: $g_{G,t+1} \equiv A_{G,t+1}/A_{G,t} = 1 + \chi INV_{G,t}^{\zeta} \uparrow$.
- If monetary policy not too restrictive then consumption also higher (combine bond Euler+int. rate rule).
- $Y_t \uparrow = C_t \uparrow + INV_{G,t} \uparrow + x_{G,t} \uparrow + x_{B,t} \downarrow\downarrow$.
- $GDP_t \uparrow = Y_t \uparrow - x_{B,t} \downarrow\downarrow - x_{G,t} \uparrow = C_t \uparrow + INV_{G,t} \uparrow$

Intuition on the mechanism

- Green input decomposition:
  $x_{G,t} = x_{G,t}/x_{B,t} * x_{B,t} = (1+\tau_t)^{\alpha/(1-\alpha)+1} \alpha^{2/(1-\alpha)} L_t \uparrow$
- $Profit_{G,t} = markup * x_{G,t} \uparrow$; Labour: $x_{G,t} = \alpha^{2/(1-\alpha)} L_t \uparrow$
- Investment Euler: $INV_{G,t} = \left[\sum_{t=0}^{\infty} \prod_{j=1}^{t} \frac{1}{1+r_j+\eta} \left(Profit_{G,t}\right)\right]^{\zeta/(1-\zeta)} \uparrow$.
- Growth equation: $g_{G,t+1} \equiv A_{G,t+1}/A_{G,t} = 1 + \chi INV_{G,t}^{\zeta} \uparrow$.
- If monetary policy not too restrictive then consumption also higher (combine bond Euler+int. rate rule).
- $Y_t \uparrow = C_t \uparrow + INV_{G,t} \uparrow + x_{G,t} \uparrow + x_{B,t} \downarrow\downarrow$.
- $GDP_t \uparrow = Y_t \uparrow - x_{B,t} \downarrow\downarrow - x_{G,t} \uparrow = C_t \uparrow + INV_{G,t} \uparrow$

Intuition on the mechanism

- Green input decomposition:
  $x_{G,t} = x_{G,t}/x_{B,t} * x_{B,t} = (1+\tau_t)^{\alpha/(1-\alpha)+1}\alpha^{2/(1-\alpha)}L_t \uparrow$
- $Profit_{G,t} = markup * x_{G,t} \uparrow$; Labour: $x_{G,t} = \alpha^{2/(1-\alpha)}L_t \uparrow$
- Investment Euler: $INV_{G,t} = \left[\sum_{t=0}^{\infty}\prod_{j=1}^{t}\frac{1}{1+r_j+\eta}\left(Profit_{G,t}\right)\right]^{\zeta/(1-\zeta)} \uparrow$.
- Growth equation: $g_{G,t+1} \equiv A_{G,t+1}/A_{G,t} = 1 + \chi INV_{G,t}^{\zeta} \uparrow$.
- If monetary policy not too restrictive then consumption also higher (combine bond Euler+int. rate rule).
- $Y_t \uparrow = C_t \uparrow + INV_{G,t} \uparrow + x_{G,t} \uparrow + x_{B,t} \downarrow\downarrow$.
- $GDP_t \uparrow = Y_t \uparrow - x_{B,t} \downarrow\downarrow - x_{G,t} \uparrow = C_t \uparrow + INV_{G,t} \uparrow$

Intuition on the mechanism

- Green input decomposition:
  $x_{G,t} = x_{G,t}/x_{B,t} * x_{B,t} = (1+\tau_t)^{\alpha/(1-\alpha)+1}\alpha^{2/(1-\alpha)} L_t \uparrow$
- $Profit_{G,t} = markup * x_{G,t} \uparrow$; Labour: $x_{G,t} = \alpha^{2/(1-\alpha)} L_t \uparrow$
- Investment Euler: $INV_{G,t} = \left[\sum_{t=0}^{\infty} \prod_{j=1}^{t} \frac{1}{1+r_j+\eta} \left(Profit_{G,t}\right)\right]^{\zeta/(1-\zeta)} \uparrow$.
- Growth equation: $g_{G,t+1} \equiv A_{G,t+1}/A_{G,t} = 1 + \chi INV_{G,t}^{\zeta} \uparrow$.
- If monetary policy not too restrictive then consumption also higher (combine bond Euler+int. rate rule).
- $Y_t \uparrow = C_t \uparrow + INV_{G,t} \uparrow + x_{G,t} \uparrow + x_{B,t} \downarrow\downarrow$.
- $GDP_t \uparrow = Y_t \uparrow - x_{B,t} \downarrow\downarrow - x_{G,t} \uparrow = C_t \uparrow + INV_{G,t} \uparrow$

Intuition on the mechanism

- Green input decomposition: $x_{G,t} = x_{G,t}/x_{B,t} * x_{B,t} = (1+\tau_t)^{\alpha/(1-\alpha)+1}\alpha^{2/(1-\alpha)}L_t \uparrow$
- $Profit_{G,t} = markup * x_{G,t} \uparrow$; Labour: $x_{G,t} = \alpha^{2/(1-\alpha)}L_t \uparrow$
- Investment Euler: $INV_{G,t} = \left[\sum_{t=0}^{\infty}\prod_{j=1}^{t}\frac{1}{1+r_j+\eta}\left(Profit_{G,t}\right)\right]^{\zeta/(1-\zeta)} \uparrow$.
- Growth equation: $g_{G,t+1} \equiv A_{G,t+1}/A_{G,t} = 1+\chi INV_{G,t}^{\zeta} \uparrow$.
- If monetary policy not too restrictive then consumption also higher (combine bond Euler+int. rate rule).
- $Y_t \uparrow = C_t \uparrow + INV_{G,t} \uparrow + x_{G,t} \uparrow + x_{B,t} \downarrow\downarrow$.
- $GDP_t \uparrow = Y_t \uparrow - x_{B,t} \downarrow\downarrow - x_{G,t} \uparrow = C_t \uparrow + INV_{G,t} \uparrow$

Intuition on the mechanism

- Green input decomposition: $x_{G,t} = x_{G,t}/x_{B,t} * x_{B,t} = (1+\tau_t)^{\alpha/(1-\alpha)+1}\alpha^{2/(1-\alpha)} L_t \uparrow$
- $Profit_{G,t} = markup * x_{G,t} \uparrow$; Labour: $x_{G,t} = \alpha^{2/(1-\alpha)} L_t \uparrow$
- Investment Euler: $INV_{G,t} = \left[\sum_{t=0}^{\infty} \prod_{j=1}^{t} \frac{1}{1+r_j+\eta} \left(Profit_{G,t}\right)\right]^{\zeta/(1-\zeta)} \uparrow$.
- Growth equation: $g_{G,t+1} \equiv A_{G,t+1}/A_{G,t} = 1 + \chi INV_{G,t}^{\zeta} \uparrow$.
- If monetary policy not too restrictive then consumption also higher (combine bond Euler+int. rate rule).
- $Y_t \uparrow = C_t \uparrow + INV_{G,t} \uparrow + x_{G,t} \uparrow + x_{B,t} \downarrow\downarrow$.
- $GDP_t \uparrow = Y_t \uparrow - x_{B,t} \downarrow\downarrow - x_{G,t} \uparrow = C_t \uparrow + INV_{G,t} \uparrow$

Outline

One-sector and two-sector inflation

- Nominal wage rule: $\frac{W_t}{W_{t-1}} = G\left(\frac{L_t}{L}\right)^{\xi} \Pi_{t-1}^{\lambda}$
- One sector model (all intermediary inputs are brown):

$$\Pi_t = \frac{W_t}{W_{t-1}} \left(\frac{p_{B,t}}{p_{B,t-1}}\right)^{\frac{\alpha}{1-\alpha}} \frac{1}{G_t}$$

  where $\frac{W_t}{W_{t-1}}$ is wage inflation, $p_{B,t} = \frac{1}{\alpha}(1+\tau_t)$ is the price of the brown input including markup and taxes, and G_t is the growth rate.
- Two-sector model (green and brown inputs):

$$\Pi_t = \frac{W_t}{W_{t-1}} \frac{A_{G,t-1} + A_{B,t-1}(\alpha p_{B,t-1})^{-\frac{\alpha}{1-\alpha}}}{A_{G,t} + A_{B,t}(\alpha p_{B,t})^{-\frac{\alpha}{1-\alpha}}}$$

  where $A_{G,t}$ and $A_{B,t}$ are the productivities of the green and brown

One-sector and two-sector inflation

- Nominal wage rule: $\frac{W_t}{W_{t-1}} = G\left(\frac{L_t}{L}\right)^{\xi} \Pi_{t-1}^{\lambda}$
- One sector model (all intermediary inputs are brown):

$$\Pi_t = \frac{W_t}{W_{t-1}} \left(\frac{p_{B,t}}{p_{B,t-1}}\right)^{\frac{\alpha}{1-\alpha}} \frac{1}{G_t}$$

where $\frac{W_t}{W_{t-1}}$ is wage inflation, $p_{B,t} = \frac{1}{\alpha}(1+\tau_t)$ is the price of the brown input including markup and taxes, and G_t is the growth rate.

- Two-sector model (green and brown inputs):

$$\Pi_t = \frac{W_t}{W_{t-1}} \frac{A_{G,t-1} + A_{B,t-1}(\alpha p_{B,t-1})^{-\frac{\alpha}{1-\alpha}}}{A_{G,t} + A_{B,t}(\alpha p_{B,t})^{-\frac{\alpha}{1-\alpha}}}$$

where $A_{G,t}$ and $A_{B,t}$ are the productivities of the green and brown

One-sector and two-sector inflation

- Nominal wage rule: $\frac{W_t}{W_{t-1}} = G\left(\frac{L_t}{L}\right)^{\xi} \Pi_{t-1}^{\lambda}$
- One sector model (all intermediary inputs are brown):

$$\Pi_t = \frac{W_t}{W_{t-1}} \left(\frac{p_{B,t}}{p_{B,t-1}}\right)^{\frac{\alpha}{1-\alpha}} \frac{1}{G_t}$$

where $\frac{W_t}{W_{t-1}}$ is wage inflation, $p_{B,t} = \frac{1}{\alpha}(1+\tau_t)$ is the price of the brown input including markup and taxes, and G_t is the growth rate.

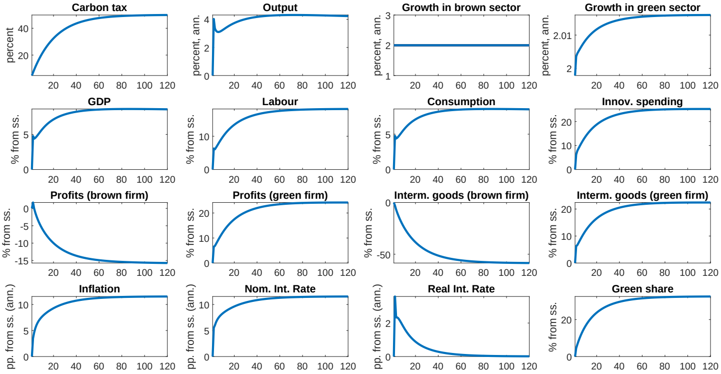
- Two-sector model (green and brown inputs):

$$\Pi_t = \frac{W_t}{W_{t-1}} \frac{A_{G,t-1} + A_{B,t-1}(\alpha p_{B,t-1})^{-\frac{\alpha}{1-\alpha}}}{A_{G,t} + A_{B,t}(\alpha p_{B,t})^{-\frac{\alpha}{1-\alpha}}}$$

where $A_{G,t}$ and $A_{B,t}$ are the productivities of the green and brown

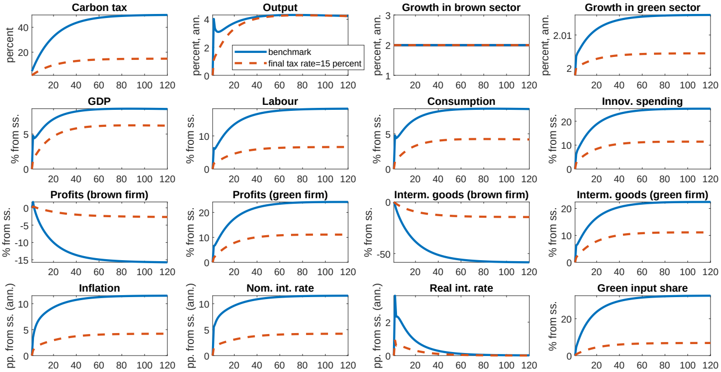
Outline

Benchmark two-sector result



Outline

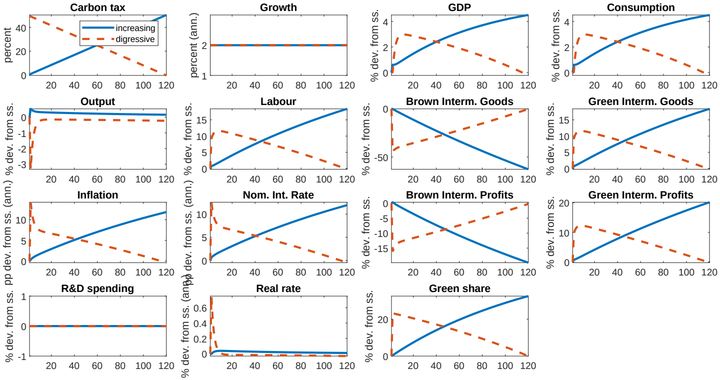
15% final tax rate instead of 50%



Outline

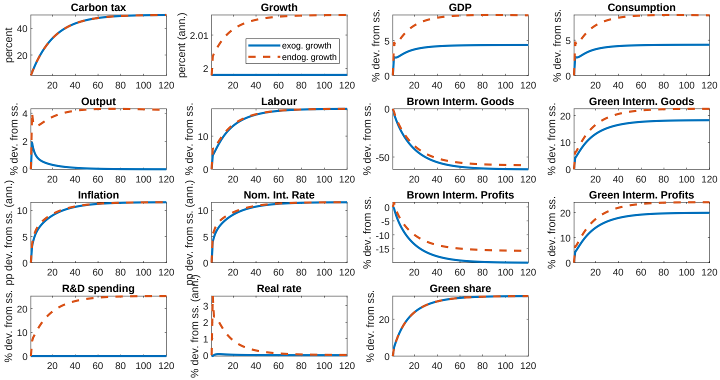
1. Motivation
   - The effects of carbon taxation on the economy
2. Model
3. Calibration
4. Results
   - The mechanism
   - Inflation from one-sector and two-sector models
   - Benchmark two-sector result
   - Size of the final tax rate
   - Exogenous growth (frontloaded or backloaded tax).
   - Endo. vs. Exo. growth (benchmark calibration)
   - Endo. vs. Exo. (higher inflation coefficient, 1.5)
   - Fiscal subsidy
5. Summary

Exogenous growth (frontloaded or backloaded tax)



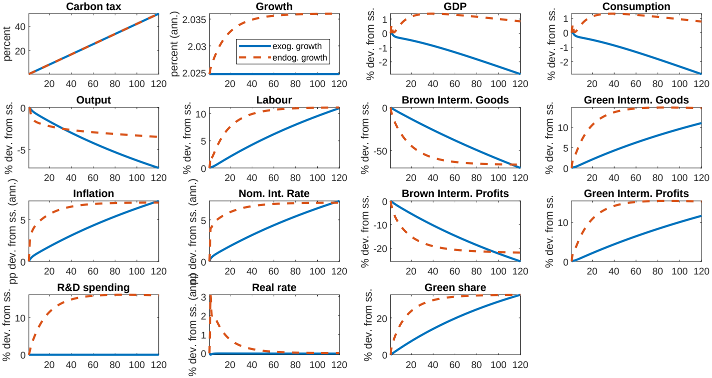
Outline

Endogenous vs. Exogenous growth



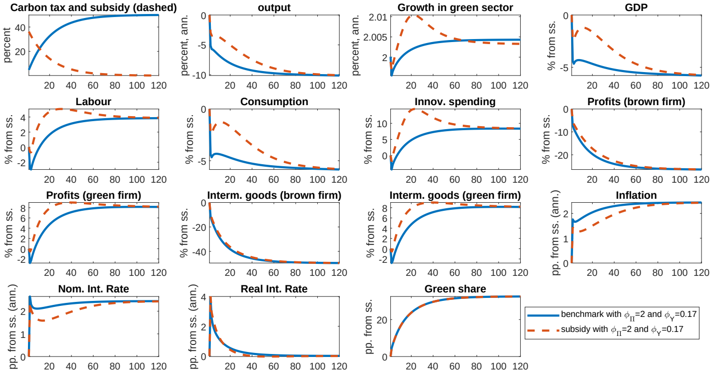
Outline

Inflation coefficient in the int. rate rule is higher (1.5) than the benchmark (1.0)



Outline

Fiscal subsidy



Summary

- Green transition is not painful as long as monetary policy is not putting high weight on inflation
- With higher weight on inflation green transition still expansive with green innovation.
- Higher final tax rate implies higher final share of green inputs
- Fiscal policy has limited scope: business protecting subsidies.
- Our main message survives in the medium-size model of Boehl et al. 2024 and less sensitive to inflation coefficient there