Is the Green Transition Inflationary?

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Question

Will the *green transition* (**taxes on polluting industries**) result in higher inflation? (Schnabel, 2022)

Answer: conceptual

- The green transition does not force monetary policymakers to tolerate higher inflation, but can generate a **tradeoff** (inflation vs. output gap)

- Tradeoff depends on the interaction of **relative stickiness** and the **I/O network**

  - Green transition requires an increase in the *relative* price of 'dirty' sectors—sectors that are *directly* (eg, oil) or *indirectly (via the I/O network)* affected by the tax

  - If *stickiness was the same* in all sectors, **inflation would be zero or negative** when policy closes the output gap: relative prices do all the work

  - If *'dirty' prices are more flexible relative to 'other' prices*, the adjustment in relative prices requires either **inflation**, if the gap is closed, or a **recession** to force 'other' prices down

Answer: quantitative

$\sim$ *70-sector* calibrated *network* model

- The carbon tax **propagates** through the I/O matrix
- Even if (dirty) energy is not a major input for the economy as a whole, it is an important input for some sectors which are *central* to the rest of the economy

- A gradual increase in carbon taxes from \$0 to \$100 would generate a **sizable tradeoff**
  - *Core inflation would be 50 to 100 bps higher than target for $\approx$ 10 years* if policy closes the output gap
  - *Inflation can only stabilized at a cost of a sizable contraction in economic activity*

Related literature

- **Empirical**
  - Känzig (2022) finds *significant effects of carbon tax on inflation*, while Konradt and Weder di Mauro (2021) find none
- **Theoretical**
  - **Olovsson and Vestin (2023)** use simple two-sector NK model to study the tradeoffs faced by monetary policymakers during the green transition
  - Bartocci et al. (2022) two-country DSGE with an energy sector and show that an increase in carbon tax dampens output; Ferrari and Nispi Landi (2022) point to importance of expectations on whether taxes are inflationary or not; 2022 WEO Ch 3: "**Climate policies have a limited impact on output and inflation and thus do not present a significant challenge for central banks**."
  - *Normative*: Nakov and Thomas (2023) investigate the normative question of whether central banks should fight climate change. Ferrari and Pagliari (2021) and Airaudo et al. (2023) consider optimal policy under the the green transition in the world economy and in a small open economy, respectively.

Related literature

- In the **two-sector** models used so far in the literature the "*Aoki* (2001) *consensus*" prevails
  - The carbon tax may have an effect on headline inflation, but its effect on core inflation is muted since the (*direct*) share of (dirty) energy as an input for the economy is relatively *small*
  - Hence policymakers should ignore it
- We show that accounting for the network reverses this conclusions

Analytical results

Simple New Keynesian I/O model

- Households' utility depends on $(\ln c_t - bL_t)$, where $c_t = y_t$ (no capital) and steady state expenditure shares $\boldsymbol{\gamma}$ $(\gamma'\mathbf{1} = 1)$. Intratemporal condition implies: $w_t = y_t$

- Each sector is monopolistically competitive with *nominal rigidities* κ *varying across sectors*; Cobb-Douglas production function with weights $\boldsymbol{\alpha}$ on labor and Ω on intermediate inputs

$$\boldsymbol{\pi_t} = K(\boldsymbol{\alpha} y_t - (I - \Omega)\boldsymbol{s_t} + \boldsymbol{\epsilon}\tau_t) + \beta \boldsymbol{E}_t \boldsymbol{\pi_{t+1}}$$

  where K is a diagonal matrix with PC slopes κ_i on the diagonal, $\boldsymbol{\alpha} + \Omega\mathbf{1} = \mathbf{1}$, and relative prices $\boldsymbol{s_t}$ follow $\boldsymbol{s_t} = \boldsymbol{s_{t-1}} + \boldsymbol{\pi_t} - \mathbf{1}\gamma'\boldsymbol{\pi_t}$

- Green transition = **tax** τ_t on "dirty sectors" to reduce dirty output (and therefore emissions), where $\boldsymbol{\epsilon}$ is the vector capturing the extent to which sectors are taxed (eg, proportional to emissions). Tax revenues are remitted lump sum to households.

Flexible prices equilibrium

- Potential output *de*creases

$$y_t^* = -\gamma'(I - \Omega)^{-1}\epsilon\tau_t$$

  where $(I - \Omega)^{-1}\epsilon$ captures *both the direct and indirect* (via Ω) effect of taxation on marginal costs

- and relative price of the sectors (directly or indirectly) affected by the tax *in*creases:

$$\boldsymbol{s}_t^* = \underbrace{(I - \Omega)^{-1}\epsilon\tau_t}_{\uparrow} + \underbrace{\mathbf{1}y_t^*}_{\downarrow}$$

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- With flexible prices, the adjustment in relative prices can take place for *any level of aggregate inflation*

$\Rightarrow$ **(relative) stickiness is key** to understand inflationary implications of the green transition

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⇒ **(relative) stickiness is key** to understand inflationary implications of the green transition

- The PC system can be expressed as: $\boldsymbol{\pi_t} = K(\boldsymbol{\alpha}(y_t - y_t^*) - (I-\Omega)(\boldsymbol{s_t} - \boldsymbol{s_t^*})) + \beta \boldsymbol{E}_t \boldsymbol{\pi_{t+1}}$
- *If* $y_t = y_t^*$, $\boldsymbol{\lambda}' K^{-1}\boldsymbol{\pi}_t = 0$ where $\boldsymbol{\lambda}' = \gamma'(I-\Omega)^{-1}$ are the Domar weights, and $\boldsymbol{\lambda}' K^{-1}$ are the "divine coincidence" weights (Rubbo 2023)

Some analytical results

- Assume that the carbon tax grows linearly forever ($\sim$ policy along the transition):

$$\tau_t = \tau_{t-1} + g$$

- **Proposition**: If policy closes the output gap ($y_t = y_t^*$), in response to a constantly growing carbon tax, the growth rates of relative prices converge to

$$\Delta \boldsymbol{s} = \left(I - \mathbf{1}\gamma'\right)\left(I - \Omega\right)^{-1} \boldsymbol{\epsilon} g$$

  while aggregate and sectoral inflation rates converge to:

$$\pi^{cpi} = \boldsymbol{\gamma}'\boldsymbol{\pi} = \left[\gamma' - \frac{\boldsymbol{\lambda}' K^{-1}}{\boldsymbol{\lambda}' K^{-1}\mathbf{1}}\right]\left(1 - \Omega\right)^{-1} \boldsymbol{\epsilon} g$$

No IO, same price stickiness

$$K = \kappa I,\ \Omega = \mathbf{0}_{n\times n}$$

- **Under $y_t = y_t^*$ aggregate inflation is zero**!

$$\pi^{cpi} = 0$$

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- Intuition from a two-sector model (dirty and other). The Phillips curves are:

$$\pi_t^d = \kappa^d(y_t - y_t^* - \underbrace{(s_t^d - s_t^{d*})}_{<0}) + \beta \boldsymbol{E}_t \pi_{t+1}^d$$

$$\pi_t^o = \kappa^o(y_t - y_t^* - \underbrace{(s_t^o - s_t^{o*})}_{>0}) + \beta \boldsymbol{E}_t \pi_{t+1}^o$$

- If $\kappa^d = \kappa^o$ and $y_t = y_t^*$

$$\pi_t^{cpi} = \gamma_o \pi_t^o + \gamma_d \pi_t^d = 0$$

since $\boldsymbol{\gamma}' \boldsymbol{s}_t = \boldsymbol{\gamma}' \boldsymbol{s}_t^* = 0$

All the work is done by relative prices!

IO, same price stickiness

$$K = \kappa I,\ \Omega \neq \mathbf{0}_{n\times n}$$

- **Under $y_t = y_t^*$ aggregate PPI inflation is zero, but CPI inflation is likely negative**!

$$\pi^{ppi} = \boldsymbol{\lambda}'\boldsymbol{\pi} = 0,\ \ \pi^{cpi} = -\frac{\boldsymbol{\lambda}'\Delta \boldsymbol{s}}{\boldsymbol{\lambda}'\mathbf{1}} = \left(\gamma' - \frac{1}{\boldsymbol{\lambda}'\mathbf{1}}\boldsymbol{\lambda}'\right) \underbrace{(I-\Omega)^{-1}\boldsymbol{\epsilon}}_{\text{direct + indirect}}\ g < 0$$

if sectors with higher (both direct and indirect) taxes have a higher consumption weight than their Domar weight —that is, *if more heavily taxed sectors are upstream*

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  if sectors with higher (both direct and indirect) taxes have a higher consumption weight than their Domar weight —that is, *if more heavily taxed sectors are upstream*

- In a two-sector model where dirty is an intermediate input for other (but not viceversa) we have:

$$\pi_t^d = \kappa(y_t - y_t^* - (s_t^d - s_t^{d*})) + \beta \boldsymbol{E}_t \pi_{t+1}^d$$
$$\pi_t^o = \kappa((1-\omega_{od})(y_t - y_t^*) - (s_t^o - s_t^{o*}) + \underbrace{\omega_{od}(s_t^d - s_t^{d*})}_{<0}) + \beta \boldsymbol{E}_t \pi_{t+1}^o$$

- If for all t $y_t = y_t^*$, while $s_t^d < s_t^{d*}$

$$\pi_t^{cpi} = \gamma_o \pi_t^o + \gamma_d \pi_t^d = \gamma_o \kappa \omega_{od} \sum_{k=0}^{\infty} \beta^k \underbrace{(s_{t+k}^d - s_{t+k}^{d*})}_{<0}$$

No IO, different price stickiness

$\Omega = \mathbf{0}_{n\times n}$ but different κ's

- Aggregate inflation is given by

$$\pi^{cpi} = \left[\gamma' - \frac{\gamma' K^{-1}}{\gamma' K^{-1}\mathbf{1}}\right] \boldsymbol{\epsilon} g = \frac{1}{\sum_j \gamma_j \kappa_j^{-1}} \sum_i \gamma_i \epsilon_i \left(\sum_j \gamma_j \kappa_j^{-1} - \kappa_i^{-1} \right) g$$

- Inflation is positive if *sectors with higher taxes (ϵ_i) have more flexible prices (lower κ_i^{-1}) than the average sector*

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- Inflation is positive if *sectors with higher taxes* (ϵ_i) *have more flexible prices (lower* κ_i^{-1}*) than the average sector*
- In a two-sector model with *fully flexible* dirty and *sticky* other:

$$s_t^d - s_t^{d*} = y_t - y_t^*$$
$$\pi_t^o = \kappa^o(y_t - y_t^* - (s_t^o - s_t^{o*})) + \beta \boldsymbol{E}_t \pi_{t+1}^o$$
$$\pi_t^{cpi} = \pi_t^o - \Delta s_t^o$$

- If $y_t = y_t^*$ then $\pi_t^{cpi} = -\Delta s_t^o > 0$. Having $\pi_t^{cpi} = 0$ requires a negative output gap $y_t < y_t^*$
- No tradeoff between stabilizing "core" ($\pi_t^o = 0$) and closing output gap (Aoki 2011, Olovsson and Vestin 2023)

General case

- CPI inflation is positive if sectors with higher (both direct and indirect) taxes have a higher consumption weight than their *divine coincidence* weight (low for flexible sectors, higher for upstream sectors)

$$\pi^{cpi} = \left[\gamma' - \frac{\boldsymbol{\lambda}' K^{-1}}{\boldsymbol{\lambda}' K^{-1}\mathbf{1}}\right] \underbrace{(I - \Omega)^{-1}\boldsymbol{\epsilon}}_{\text{direct + indirect}} \; g$$

back

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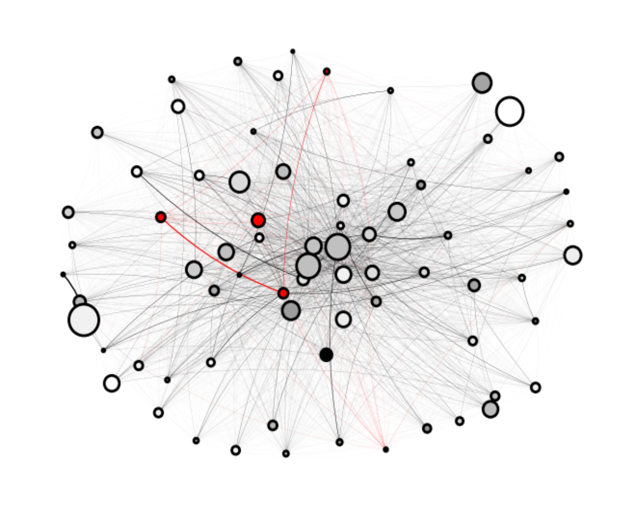
back

- Bottom line: **the interaction between relative stickiness** $(\gamma' - \frac{\boldsymbol{\lambda}' K^{-1}}{\boldsymbol{\lambda}' K^{-1}\mathbf{1}})$ **and the propagation via the IO network** $((I - \Omega)^{-1}\boldsymbol{\epsilon} \neq \Omega\boldsymbol{\epsilon})$ **is key for the inflationary impact of the carbon tax**
- Network literature studying inflation (La'O & Tahbaz-Salehi, 2022; Rubbo, 2023; Afrouzi and Bhattarai, 2023): inflation-output tradeoff depends on interaction of heterogeneity in stickiness and I/O links

The quantitative I/O model

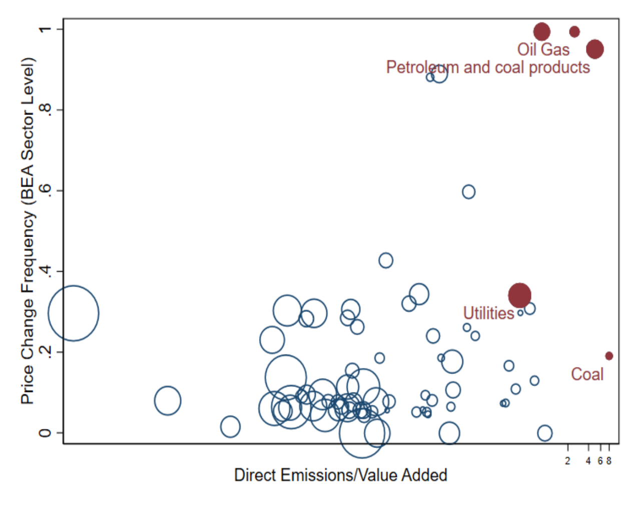
Features of the U.S. I/O network

1. Energy is **central**



Features of the U.S. I/O network

2. Heterogeneity across sectors in the relationship between 'dirtiness' and stickiness
    - Dirty sectors tend to be more flexible, but some dirty sectors are quite sticky



The I/O model

- Nested CES structure:
  - Firms in sector i produce using CES aggregate of labor and intermediate inputs (w elasticity η)

$$X_t^i = A_t^i \left[\alpha_i^{\frac{1}{\eta}} (L_t^i)^{\frac{\eta-1}{\eta}} + (1-\alpha_i)^{\frac{1}{\eta}} (I_t^i)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

  - Intermediate inputs are aggregate (w elasticity ν) of energy and non-energy inputs, each of which is aggregate of sectoral output (w elasticity ξ):

$$I_t^i = \left[\varsigma_i^{\frac{1}{\nu}} (E_t^i)^{\frac{\nu-1}{\nu}} + (1-\varsigma_i)^{\frac{1}{\nu}} (N_t^i)^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}}$$

and

$$E_t^i = \left[\sum_j (\omega_{ij}^E)^{\frac{1}{\xi}} (X_t^{ij})^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}}, \quad N_t^i = \left[\sum_j (\omega_{ij}^N)^{\frac{1}{\xi}} (X_t^{ij})^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}}$$

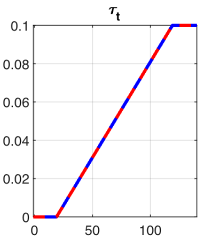
  - Consumption is CES aggregate (ζ)

$$C_t = \left[\sum_i (\gamma_i)^{\frac{1}{\zeta}} (C_t^i)^{\frac{\zeta-1}{\zeta}} \right]^{\frac{\zeta}{\zeta-1}}$$

Calibration

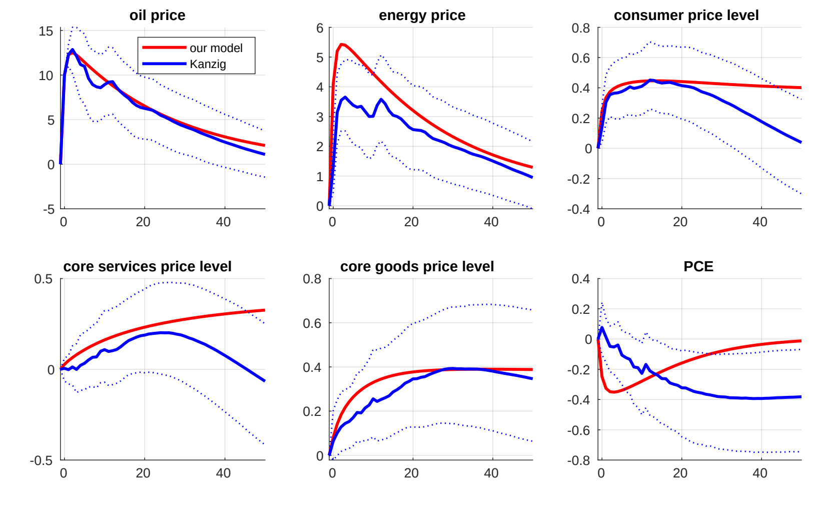
- Consumption shares and sectoral input-output linkages: BEA 2012 input-output tables
- Monthly frequencies of price adjustment by sector $1-\theta_i$: Cotton and Garga (2022)
- Carbon tax levied upstream on oil & gas extraction and coal mining based on *raw* CO_2 *emissions* (from EIA energy usage data and EPA emissions intensity data)
- Key elasticities taken from the literature: $\nu = 0.2$ (Bachmann et al. 2022); $\xi = 0.1$ (Atalay 2017); $\eta = 0.6$ (Oberfield and Raval 2021); $\zeta = 2$ (Hobijn and Nechio 2019)

- Tax gradually increases from 0 to 100 \$ over 100 months ($\sim$ carbon pricing policy scenario in Barron et al., 2018), anticipated 20 months in advance



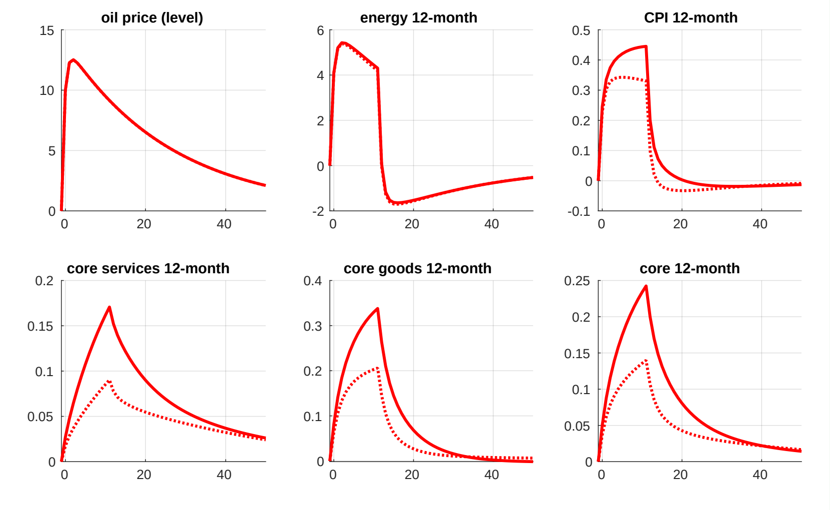
Validation: Model vs Känzig's energy price shock

- Compare the effect of WTI oil price shocks in the model to those estimated by Känzig (AER 2022)
- Markup process in the model calibrated to match oil price IRFs in Kanzig; propagation is driven by the model with no attempt toward "estimation" of the model parameters
- Model matches *levels* surprisingly well, at least up to 2 years



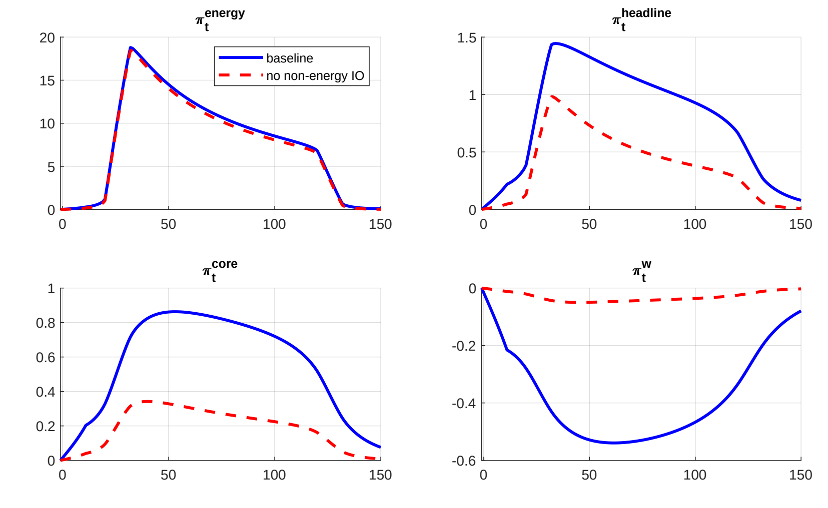
Propagation via the I/O network

- Solid red: same IRFs as above but in terms of 12-month inflation (except for oil)
- Dotted red: **counterfactual** without I/O network *except* for energy (400 sectors)
- For *core* (and services), **network is half of the story**



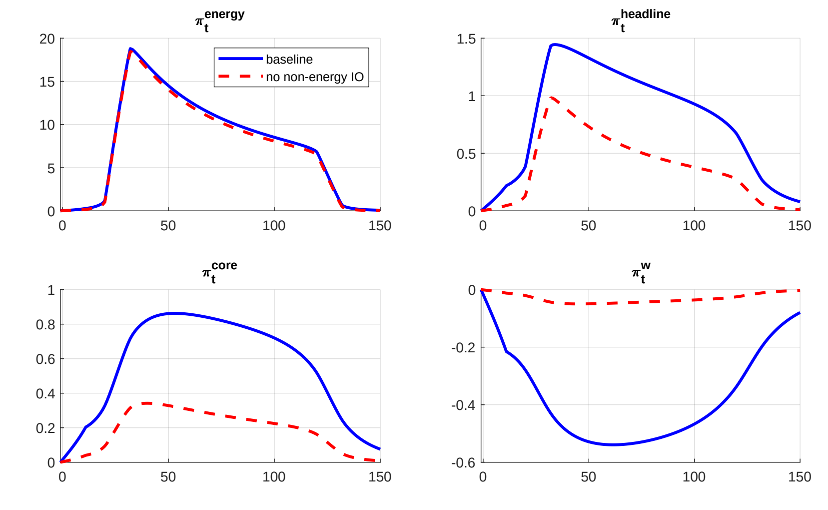
Non-linear dynamics under *output gap* targeting

- Focusing on the blue line, the tax has **substantial inflationary implications**
- 12 month *headline* CPI is *one percent or more above target* for more than *6 years*
- 12 month *core* CPI is *.5 percent or more above target* for about *10 years* (and .8 or more above target for about 3)



Propagation via the I/O network

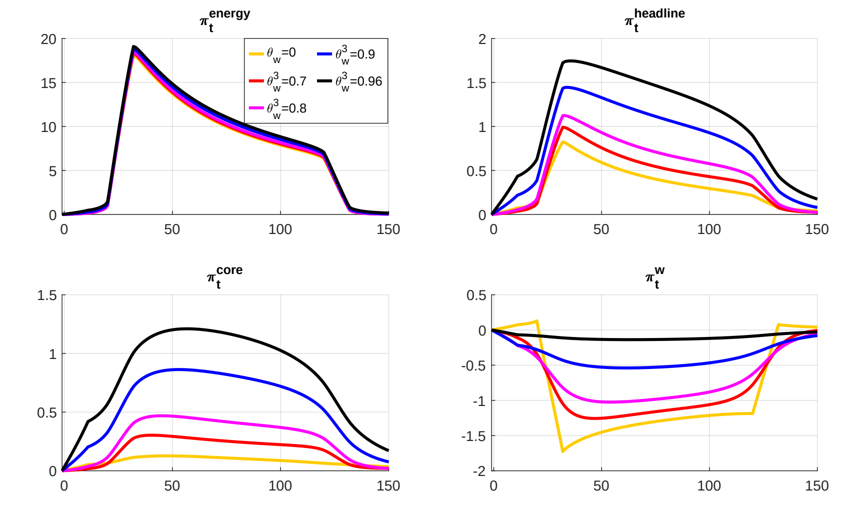
- Dashed red: **counterfactual** without I/O network *except* for energy
- For *headline* **network** accounts for btw one third and half of the responses
- For *core* **network is two thirds of the impact**



Importance of wage stickiness

- Without wage stickiness, the fall in wages compensates the increased energy costs → little happens to core inflation

- With elevated (but still reasonable) wage stickiness, effect on headline and core inflation is large



Analytics

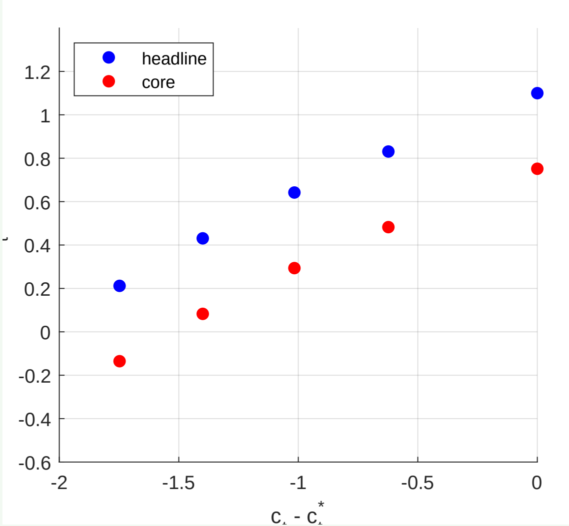
Tradeoffs in the quantitative I/O model

- Tradeoffs are unfavorable to the central bank
- controlling **headline** inflation (eg, $< .6$ on average for more than 8 years) takes a 1 percent average *"output" gap* over the same period
- controlling **core** inflation (eg, $< .5$) leads to a $>.5$ percent *contraction*

Robustness to elasticities

Emissions

100 months



Summing Up

- Green transition generates a **trade-off between real activity and inflation**

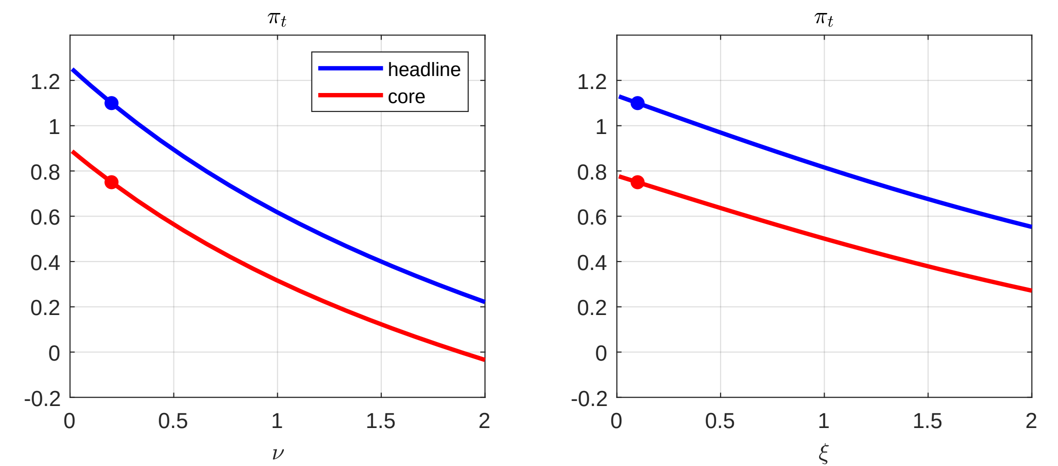
- Following a gradual increase in carbon taxes from \$0 to \$100
    - *Core* inflation would be 50 to 100 bps higher than target for $\approx$ 10 years
    - Inflation can only stabilized at a cost of a sizable contraction in economic activity

- The interaction of **relative stickiness** and the **I/O network** is key

Thank you!

Robustness to the elasticities

Average inflation during 100 months of tax increase



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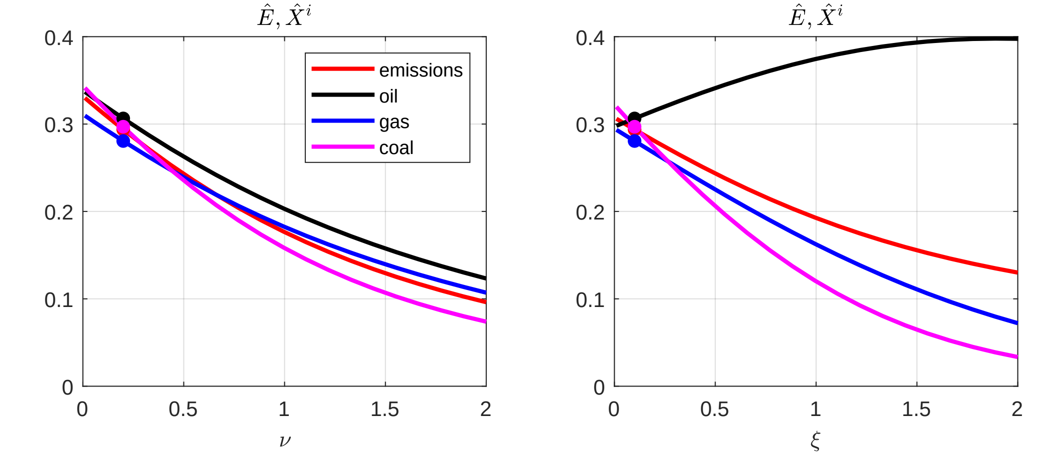
Emissions as a function of the elasticity of substitution

Eventual reduction in emissions



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