The Missing Intercept

A Sufficient Statistics Approach to General Equilibrium Effects

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Motivation

- Recent literature: **micro data** for **macro shocks**
  - Often focussed on shocks to household & firm spending
  - Well-known examples: income tax rebate, bonus depreciation

- Key limitation: **micro estimand** $\neq$ **macro counterfactual**

  $\rightarrow$ Formal interpretation: **DiD** estimand = **PE** response

  PE $\rightarrow$ **GE** through model: specification? calibration?

- This paper: can we learn about the **GE intercept** without a model?

A Sufficient Statistics Approach

Q: What's the consumption response to a transfer ε_b?

- Main result: measurement of the **GE intercept**

$$\text{C response} = \underbrace{\text{direct response to } \varepsilon_b}_{\textbf{DiD estimand}} + \underbrace{\text{C response to G}}_{\textbf{LP/VAR estimand}}$$

  - Intuition: private & public spending shocks share similar GE propagation
  - Exactly valid in large model class, approximate with further generalizations

    RBC, Medium-Scale NK-DSGE, HANK, Heterogeneous Firms, . . .

Sufficient statistic: model matters *only* through DiD and G IRFs

- **A**: large **direct response** + limited **GE feedback** = **big increase**

Outline

1. Sufficient Statistics Decomposition
   - Exact Demand Equivalence
   - Approximation Accuracy

2. Application: Income Tax Rebate

3. Beyond Tax Rebates

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A Simple Example

- Illustration in mini model: **spender-saver RBC**
  1. Households: spenders & savers, inelastic labor supply, log preferences
  2. Production: competitive representative firm, owned by savers, $y = f(k, \ell)$
  3. Government: consume final good & lump-sum tax (on savers)

- Two shocks: **transfer ε_b** to spenders, increase in **gov't spending ε_g**

  $\rightarrow$ Size: one period, equal to 1% of steady-state consumption

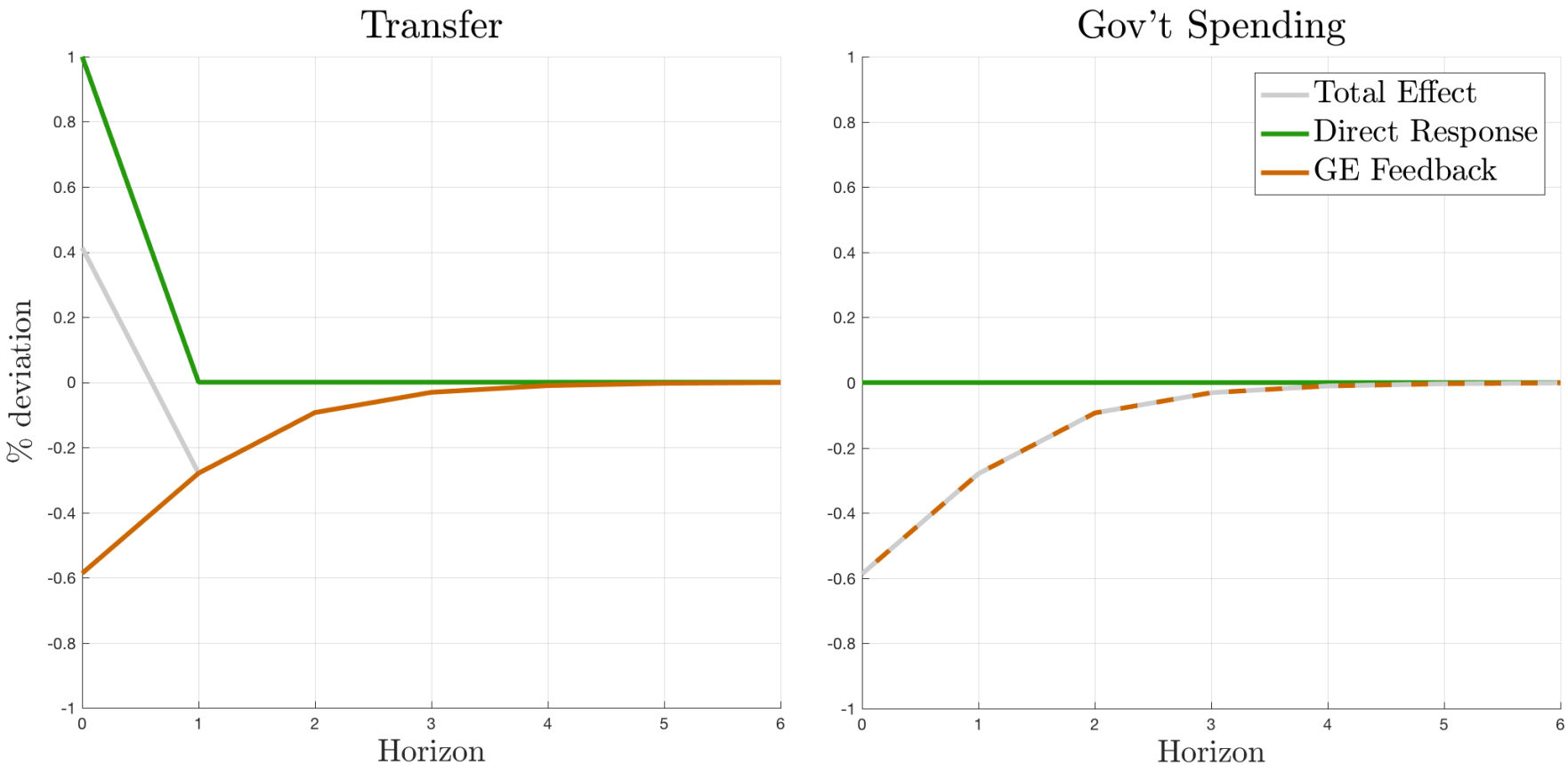
- **PE**-**GE** decomposition of consumption impulse response:

$$\mathbf{c}_b = \underbrace{\mathbf{c}(\bar{\mathbf{m}}, \bar{\mathbf{r}}, \boldsymbol{\varepsilon}_b)}_{\text{PE Impact}} + \underbrace{\mathbf{c}(\mathbf{m}, \mathbf{r}, \bar{\boldsymbol{\varepsilon}}_b)}_{\text{GE Feedback}}$$

  - HH's receive post-tax income **m**, earn return **r**, & receive transfer $\boldsymbol{\varepsilon}_b$
  - Notation: bars denote steady state, boldface denotes *paths* $t = 0, 1, 2, \ldots$

Example IRFs

How does consumption respond to ε_b and ε_g?



$$\Rightarrow \quad c_b \quad = \quad c_b^{PE} \quad + \quad c_g$$

Proof

- Proof strategy: study perfect foresight equilibrium = 1st-order IRF

  [Boppart et al. (2018), Auclert et al. (2019), Guren et al. (2019)]

Proposition

A sequence of real rates $\mathbf{r}$ *is part of a perfect foresight equilibrium if and only if*

$$\underbrace{\mathbf{c}(\mathbf{m}(\mathbf{r}, \boldsymbol{\varepsilon}_b, \boldsymbol{\varepsilon}_g), \mathbf{r}, \boldsymbol{\varepsilon}_b) + \mathbf{g}(\boldsymbol{\varepsilon}_g)}_{\boldsymbol{D}(\boldsymbol{r};\boldsymbol{\varepsilon}_b,\boldsymbol{\varepsilon}_g)} = \underbrace{\mathbf{y}(\mathbf{r}) - \mathbf{i}(\mathbf{r})}_{\boldsymbol{S}(\boldsymbol{r})}$$

where $\mathbf{c}(\bullet)$, $\mathbf{y}(\bullet)$ *and* $\mathbf{i}(\bullet)$ *are household and firm policy functions.*

To first order:

$$\hat{\mathbf{r}} = \underbrace{[\mathbf{S}_r - \mathbf{D}_r]^{-1}}_{\text{GE adjustment}} \times \underbrace{\left[\mathbf{D}_{\varepsilon_b} \cdot \boldsymbol{\varepsilon}_b + \mathbf{D}_{\varepsilon_g} \cdot \boldsymbol{\varepsilon}_g\right]}_{\text{excess demand}}$$

Thus, if $\mathbf{c}_b^{PE} = \mathbf{g}^{PE}$, *then*

$$\mathbf{c}_b = \mathbf{c}_b^{PE} + \mathbf{c}_g$$

General Model

How general is **identical GE propagation**?

- Sketch: workhorse one-sector business-cycle model ▸ Details
  1. **Households**: uninsurable income risk, save & borrow, sticky wages
  2. **Production**: intermediate goods (real & fin. frictions) + sticky-price retailers
  3. **Government**: spend & tax, set nominal rate (debt & monetary rules)

- Nests various workhorse quantitative business-cycle models

  RBC, Medium-Scale NK-DSGE, HANK, Heterogeneous Firms . . .

- Again study GE propagation of **transfer** + **gov't spending** shocks

Demand Equivalence

- Equilibrium = solution to *many* mkt-clearing conditions + other restrictions

  [output, asset market, labor, firm valuation, Taylor rule . . .]

  $\rightarrow$ vs. simple model: one market (final good) & one price (r)

- Proof strategy: ensure identical **excess demand/supply** *in all markets*

  A1 **Output**: identical direct demand *time paths* $\mathbf{c}_b^{PE} = \mathbf{g}^{PE}$

  A2 **Gov't budget**: identical tax financing for transfers & gov't spending

  Restrictions on gov't spending shock $\boldsymbol{\varepsilon}_g$

  A3 **Labor**: no wealth effects in labor supply *or* fully sticky wages

  Restriction on model

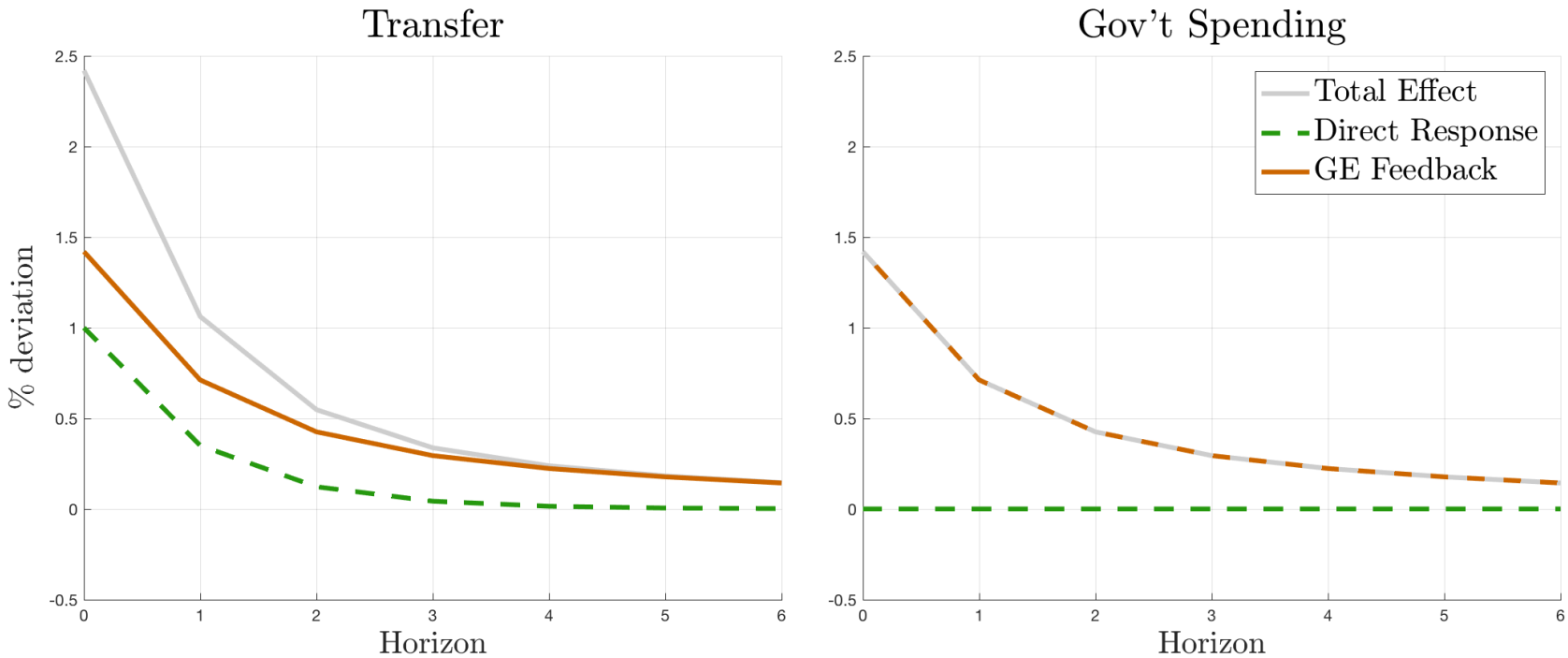
Proposition

Under A1-A3, aggregate consumption impulse responses satisfy, to first order,

$$\mathbf{c}_b \quad = \quad \mathbf{c}_b^{PE} \quad + \quad \mathbf{c}_g$$

Sufficient-Statistics Result

- Example: amplification in HANK model with GHH preferences



- Identification result: sufficient statistics for model class Θ

$$\mathbf{c}_b(\theta) \quad = \quad \mathbf{c}_b^{\text{PE}}(\text{iMPC}(\theta)) \quad + \quad \mathbf{c}_g(\theta), \quad \forall\, \theta \in \Theta$$

  - Sufficient statistics bypass specification & calibration uncertainty
  - Identify policy-relevant combinations of deep parameters [Heckman (2010)]

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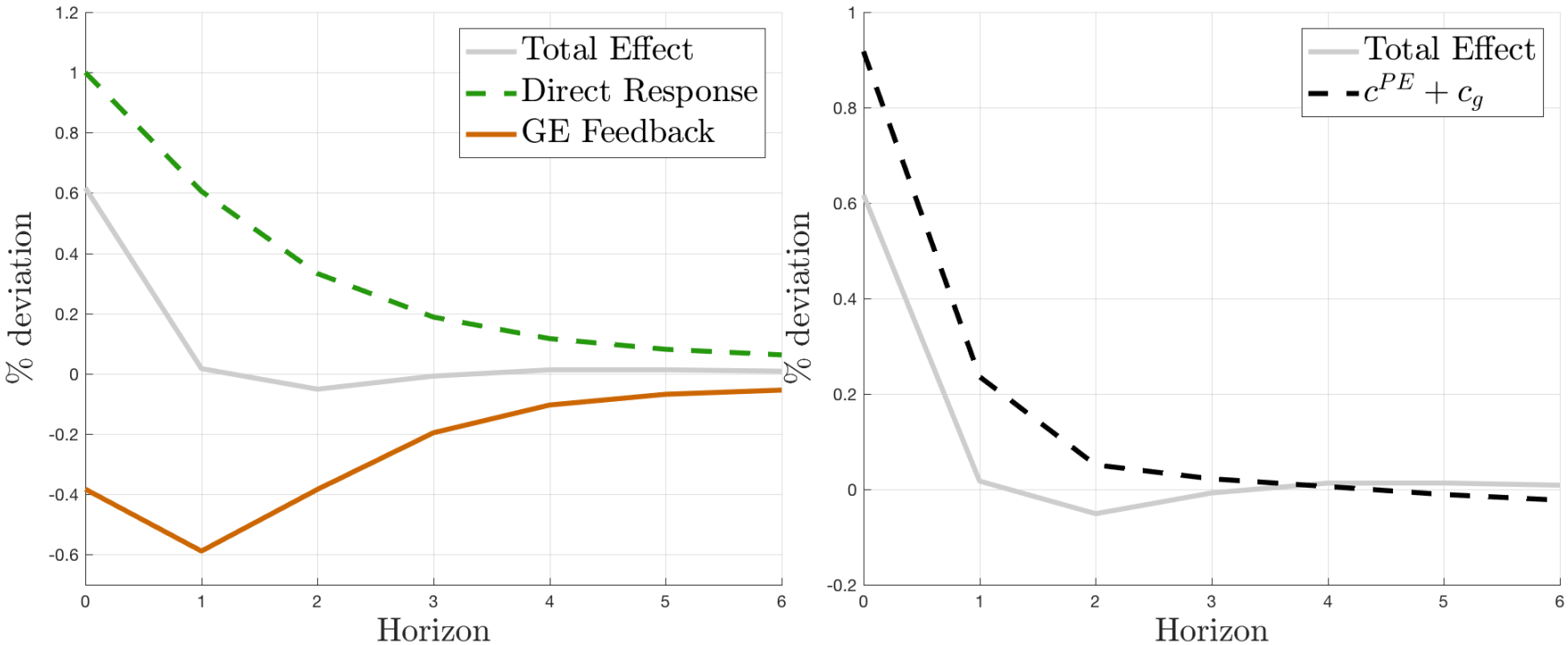
Approximation Accuracy

How well does the approximation work in **richer models**? When does it **fail**?

1. Estimated **workhorse models** [today]
   - → Baseline: estimated HANK model (using standard U.S. time series data)
   - → Alternative: canonical estimated macro models, e.g. Smets-Wouters
2. Extensions of **exact equivalence** ▸ Details
   - → Durables & non-durables in household consumption
   - → Alternative assumptions on expectation formation
3. **Approximate equivalence** in richer models ▸ Details
   - → Multiple sectors: immobile factors, het. factor incidence, rel. price responses
   - → Multiple assets: liquid vs. illiquid, borrowing wedge
   - → Valued & productive gov't spending

Breaking Demand Equivalence

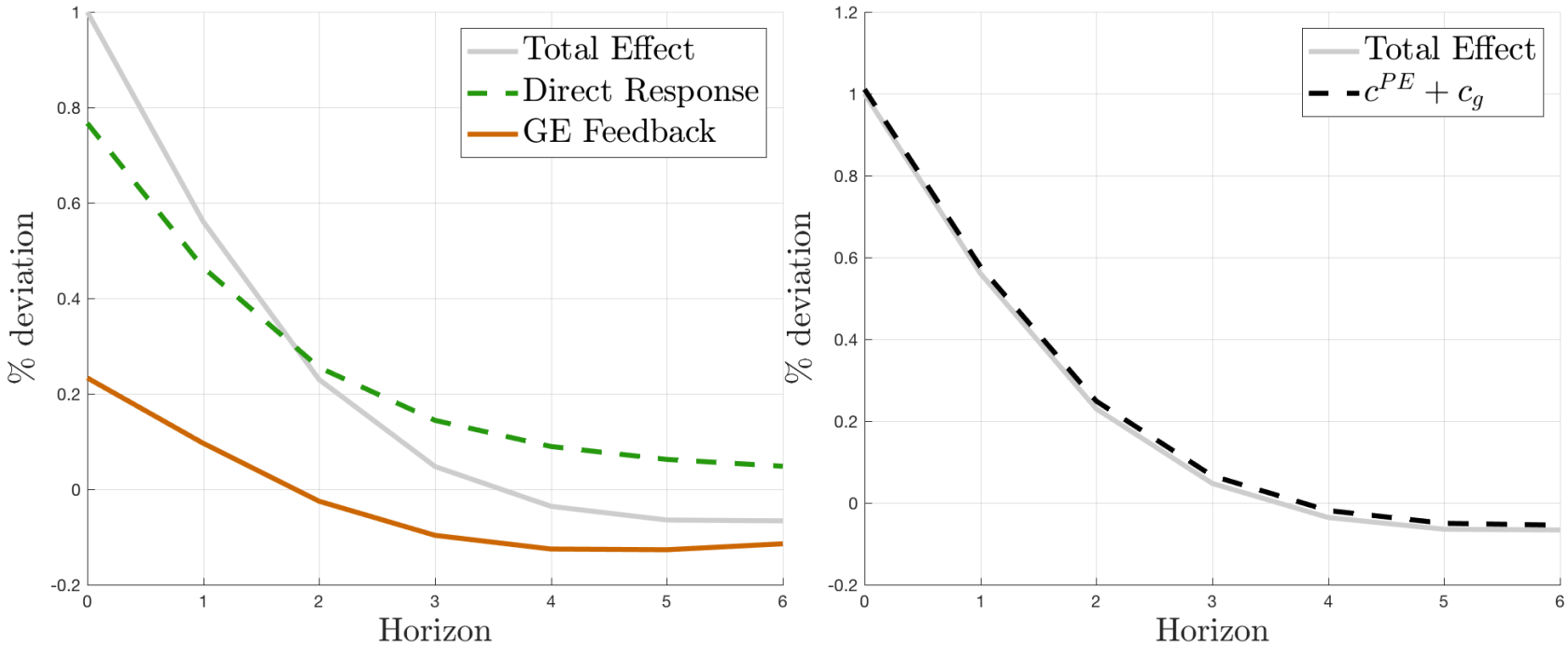
- Estimate HANK model, remove nominal rigidities, compute $\mathbf{c}_b^{\text{PE}} + \mathbf{c}_g$:



- Why does the additive decomposition overstate the GE effect?
  - After db: households *equally* increase spending and reduce hours worked
  - Inconsistent with empirical evidence: earnings 4$ ↓ for spending 100$ ↑

Estimated HANK Model

- Estimate HANK model, compute $\mathbf{c}_b^{\text{PE}} + \mathbf{c}_g$:



- Approx. demand equivalence: A3 *nearly* satisfied ▸ Details

  → Moderate wage stickiness (≈ 2-3 quarters) dampens labor supply response

  Beraja-Hurst-Ospina, Grigsby-Hurst-Yildirmaz

- Alternative: canonical quantitative macro models ▸ NK-DSGE ▸ Het-Firm ▸ RBC

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Application: Income Tax Rebate

Q: What's the consumption response to a lump-sum transfer?

- Consensus estimates of large direct spending response

  Johnson-Parker-Souleles, Parker-Souleles-Johnson-McClelland

- Aggregate effect unclear: from full crowding-out to strong amplification

  Guerrieri-Lorenzoni, Jones-Midrigan-Philippon, Auclert-Rognlie-Straub

- Instead follow the sufficient statistics approach:

$$\mathbf{c}_b \quad = \quad \mathbf{c}_b^{\text{PE}} \quad + \quad \mathbf{c}_g$$

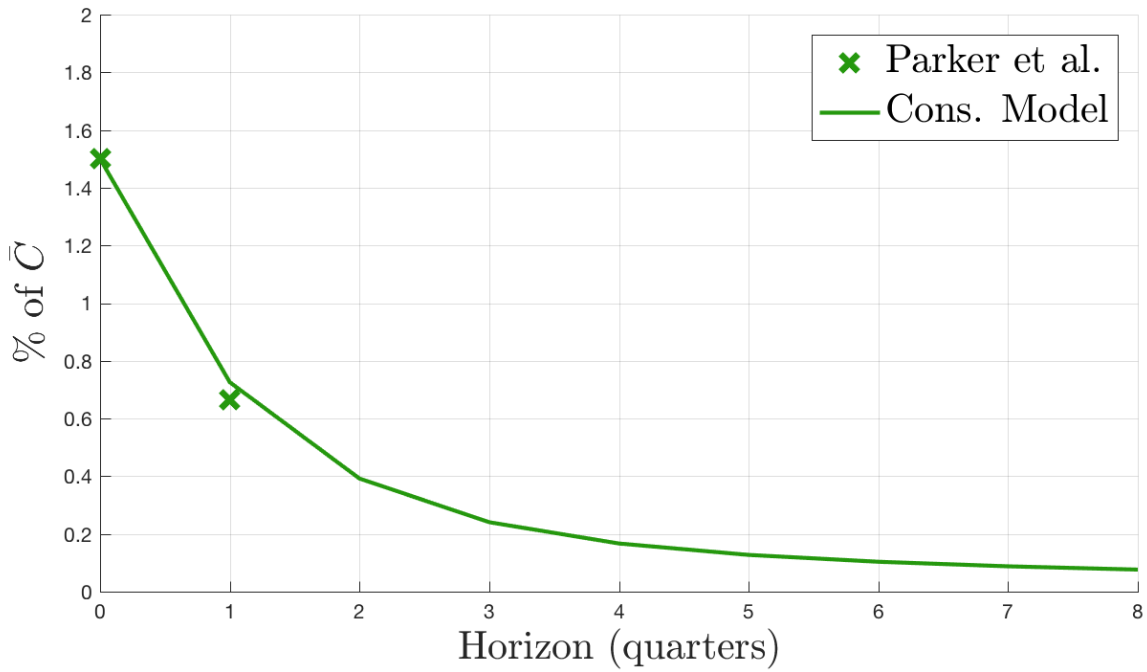
1. What's the direct response of consumption to a lump-sum transfer?
2. How does consumption respond to a deficit-financed expansion $\mathbf{g} \approx \mathbf{c}_b^{PE}$?

Step 1: PE Effect

- What we need: *path* of PE consumption response to one-off rebate
  - (β_0, β_1) (approx.) interpretable as $c^{PE}_{0:1,b}$ [Kaplan & Violante (2014)]

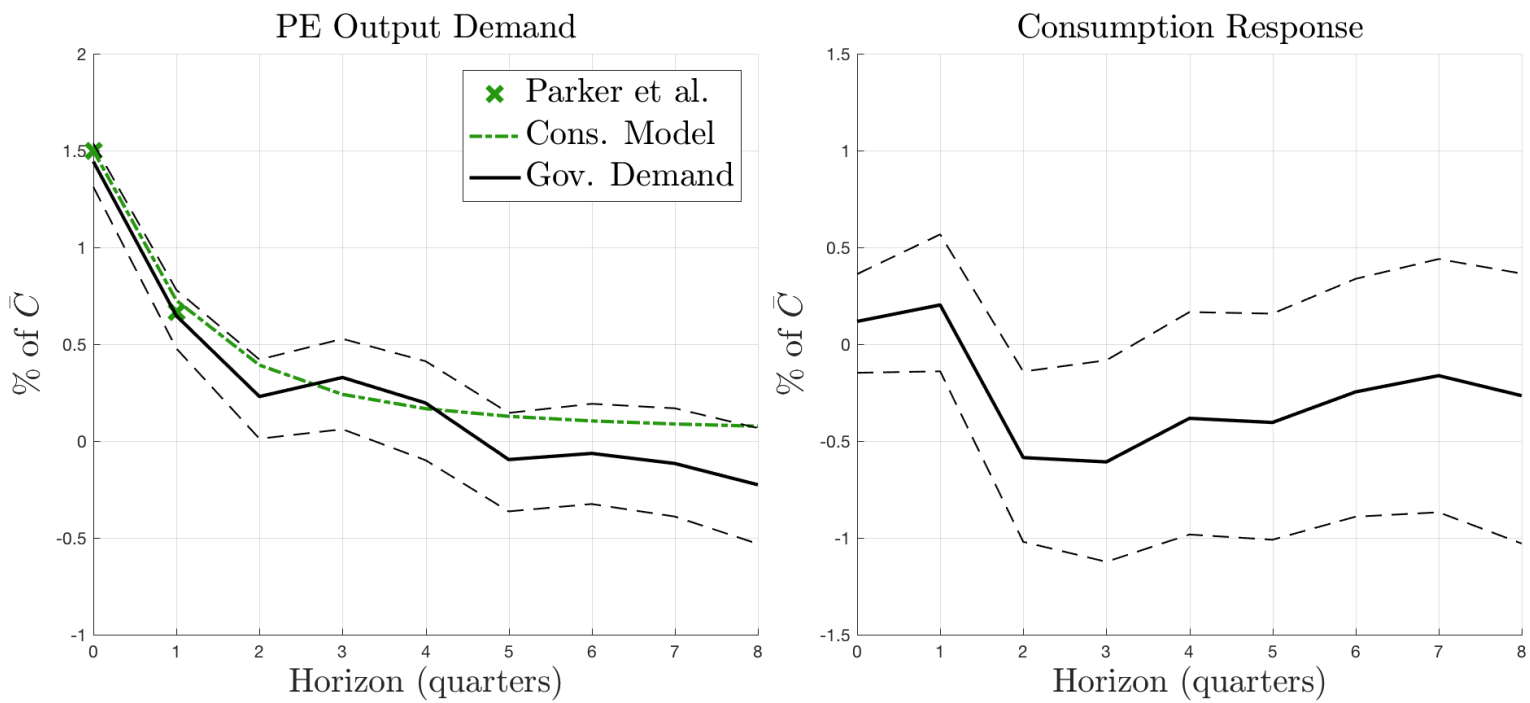
$$\Delta c_{it} = \sum_s \gamma_s \text{month}_s + \delta' X_{i,t-1} + \beta_0 R_{i,t} + \beta_1 R_{i,t-1} + \text{error}$$

  - Get more delayed iMPCs from other experiments or consumption model
- Find: significant, but short-lived expansion in consumption demand

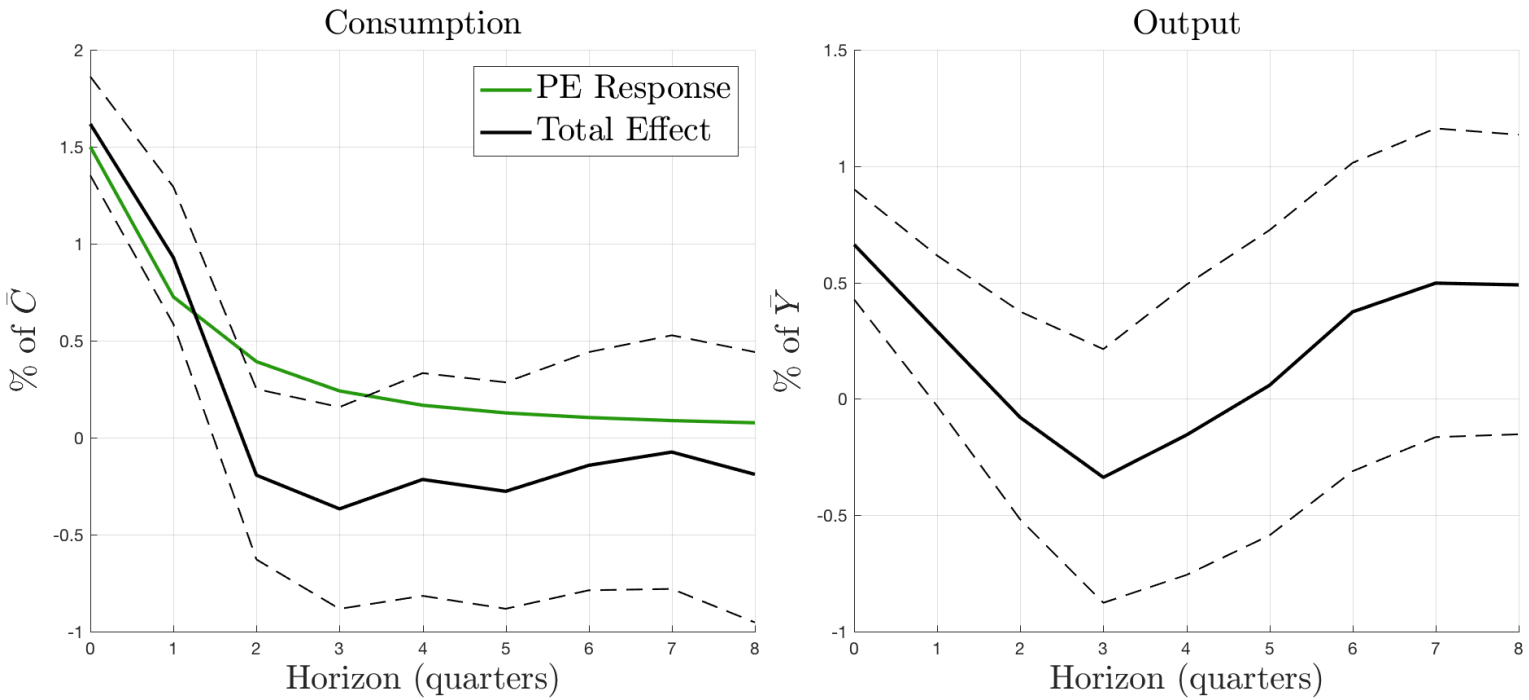


Step 2: GE Feedback

- What we need: deficit-financed expansion in gov't spending with $\mathbf{g} \approx \mathbf{c}_b^{PE}$
  - Identification assumption: gov't spending survey forecast error as macro-IV
  - Note: robust to fiscal foresight/non-invertibility [Plagborg-Møller & Wolf (2019)]
- Find: deficit ↑ for ≈ 4 yrs, unit Y multiplier, C response ≈ 0 ▸ Details



GE Counterfactual



- For one-off deficit-financed **income tax rebate**:

  consumption GE counterfactual ≈ micro estimate

  ⇒ Large (but short-lived) output and consumption boom

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Beyond Tax Rebates

1. Generalization to investment bonus depreciation ▸ Details

$$\mathbf{i}_{\tau}^{PE} - \mathbf{y}_{\tau}^{PE} \quad = \quad \sum_{s \in \mathcal{S}} \beta_s \times \mathbf{g}_s$$

   → GE equivalence result for net demand $I - Y$, exact in large model class

   Khan-Thomas, Winberry, Ottonello-Winberry

   → Implementation: $I \uparrow$ (today) & $Y \uparrow$ (later) = $G \uparrow$ (today) & $G \downarrow$ (later)

2. Theory applies to generic "consumption/investment demand" shocks

$$\text{excess demand}^{PE} \quad = \quad \sum_{s \in \mathcal{S}} \beta_s \times \mathbf{g}_s$$

   → Examples: deleveraging, redistribution, uncertainty, . . .

3. Further extension: cross-*regional* micro regressions ▸ Details

   Mian-Sufi-Rao, Guerrieri-Lorenzoni, Guren-McKay-Nakamura-Steinsson

Conclusions

How can we learn about the **missing GE intercept** of spending shocks?

1. Identify informative empirical moments for **PE**-**GE** mapping:
   - Gov't spending IRFs are useful "identified moment" for GE intercept
     Christiano-Eichenbaum-Evans, Nakamura-Steinsson
   - Intuition: similar GE accommodation of different "demand shocks"

2. Get some GE counterfactuals even without solving a model
   - Suff. statistics approach: GE counterfactual = micro DiD + macro shock IRF
   - Applications: income tax rebate [today], bonus depreciation, deleveraging

Model Details: Household Block

- Household consumption-savings problem:

$$\max \quad \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_i^t u(c_{it}, c_{it-1}, \ell_{it}) \right]$$

such that

$$c_{it} + b_{it} = (1 - \tau_t^{\ell}) w_t \ell_{it} e_{it} + \tau_{it} + \frac{1 + i_{t-1}^b}{1 + \pi_t} b_{it-1}$$

+ borr. constraint $b_{it} \geq \underline{b}$ & ℓ_{it} intermediated by sticky-wage union

- Labor supply: sticky-wage union
  - Aggregation:

$$\ell_t^h \equiv \left(\int_k \ell_{kt}^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dk \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}}$$

  - Standard algebra gives wage-NKPC:

$$\pi_t^w (1 + \pi_t^w) = \frac{\varepsilon_w}{\theta_w} \ell_t^h \left[\int_0^1 \left\{ -u_{\ell}(c_{it}, c_{it-1}, \ell_t^h) - \frac{\varepsilon_w - 1}{\varepsilon_w} (1 - \tau_{\ell}) w_t e_{it} \left\{ u_c(c_{it}, c_{it-1}, \ell_t^h) \right.\right.\right.$$
$$\left.\left.\left. + \beta e^{\varepsilon_{t+1}^b - \varepsilon_t^b} \mathbb{E}_t \left[u_{c_{-1}}(c_{it+1}, c_{it}, \ell_{t+1}^h) \right] \right\} di \right\} \right] + \beta e^{\varepsilon_{t+1}^b - \varepsilon_t^b} \pi_{t+1}^w (1 + \pi_{t+1}^w)$$

back

Model Details: Firm Block

- Overview: three-layer structure
  1. Competitive intermediate goods producers: prod. risk, real + fin. frictions
  2. Monopolistically competitive retailers, nominal rigidities
  3. Competitive aggregator of retailer goods
- Problem of intermediate goods producers:

$$\max \quad \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \left(\prod_{q=0}^{t-1} \frac{1}{1+r_q^a} \right) d_{jt}^l \right]$$

such that

$$\begin{aligned} d_{jt}^l &= p_t^l y_{jt} - w_t \ell_{jt} - \xi_{jt} \times 1_{i_{jt} \neq 0} - (1 - 1_{i_{jt}<0} \times \varphi) i_{jt} - \phi(i_{jt}, i_{jt-1}) - b_{jt}^f + \frac{1+i_{t-1}^b}{1+\pi_t} b_{jt-1}^f \\ y_{jt} &= y(e_{jt}, u_{jt} k_{jt-1}, \ell_{jt}), \quad i_{jt} = k_{jt} - [1 - \delta(u_{jt})] k_{jt-1} \\ -b_{jt}^f &\leq \Gamma(k_{jt-1}, k_{jt}, \pi_{jt}), \quad d_{jt}^l \geq \underline{d} \end{aligned}$$

- Retailers + aggregator give standard NKPC:

$$\hat{\tilde{\pi}}_t = \frac{\varepsilon_p}{\theta_p} \frac{\varepsilon_p - 1}{\varepsilon_p} \times \hat{\tilde{p}}_t^l + \beta \hat{\tilde{\pi}}_{t+1}$$

back

Model Details: Government Block

- Fiscal policy
  - Flow budget constraint:

$$\frac{1+i_{t-1}^{b}}{1+\pi_t} b_{t-1} + g_t + \tau_t = \tau_\ell w_t \ell_t + b_t$$

  - Financing rule: path $\boldsymbol{\tau}^e$ such that $\boldsymbol{\tau} = \boldsymbol{\tau}^e + \boldsymbol{\varepsilon}^\tau$, the flow government budget constraint holds at all periods t, and $\lim_{t\to\infty} \left(\prod_{s=0}^{t} \frac{1}{1+r_s}\right) b_t = 0$

- Monetary policy

$$\hat{\hat{i}}_t^b = \rho_m \hat{\hat{i}}_{t-1}^b + (1-\rho_m)\left(\phi_\pi \hat{\hat{\pi}}_t + \phi_y \hat{\hat{y}}_t + \phi_{dy} \hat{\hat{y}}_{t-1}\right)$$

back

Accuracy in Estimated HANK Model

- Labor supply response and wealth effects
  - Without A3: tax rebate = gov't spending shock + leisure shock
  - In estimated model, the implied leisure shock has negligible aggregate effects
  - Direct evidence: provide sharp lower bound through income tax shock IRFs

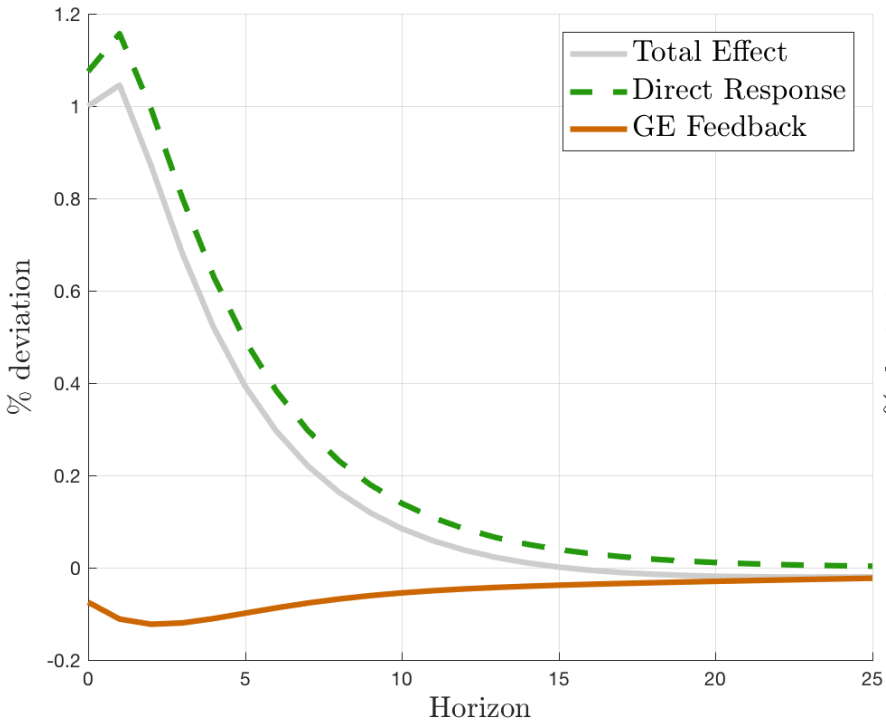
    [Mertens & Ravn (2013, 2014), Mertens & Montiel-Olea (2018)]

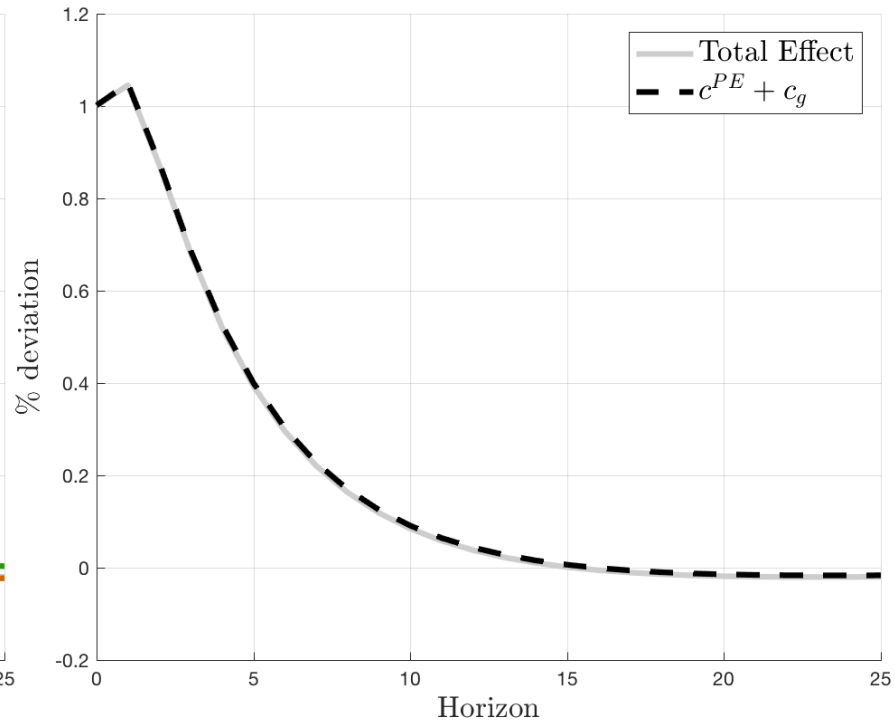
- Generalization: borrowing penalty and heterogeneous rates of return
  - Present value of household spending path is higher, since some households face rate of return $r_t^b + \kappa_b > r_t^b$
  - But: 2% quarterly return difference of $\approx 20\%$ of households changes NPV of 100$ rebate by very little

▸ back

Justiniano-Primiceri-Tambalotti (2010)

- JPT (2010) at posterior mode, study impatience & gov't spending shocks:



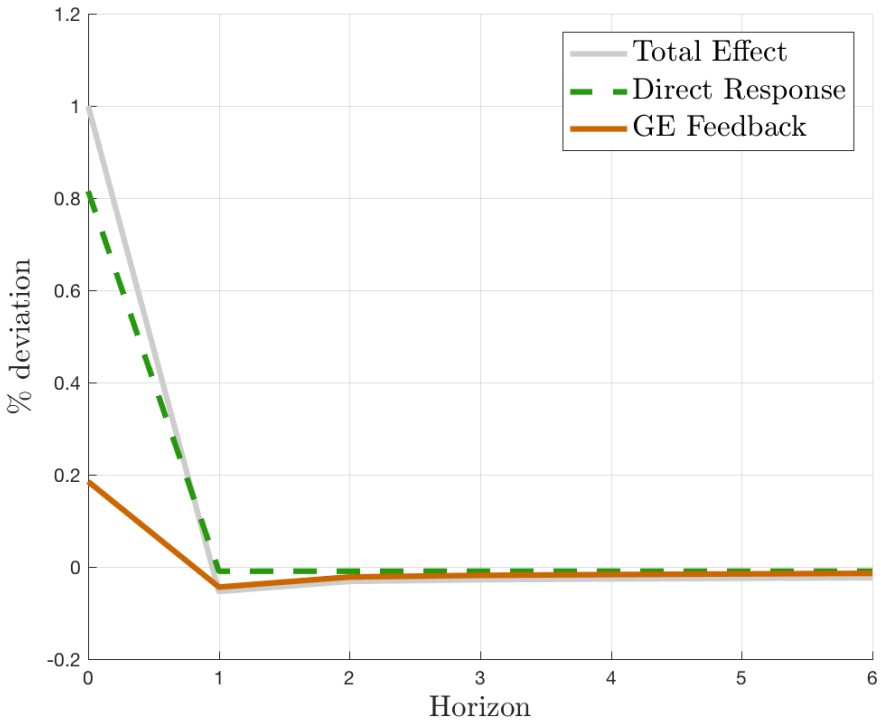


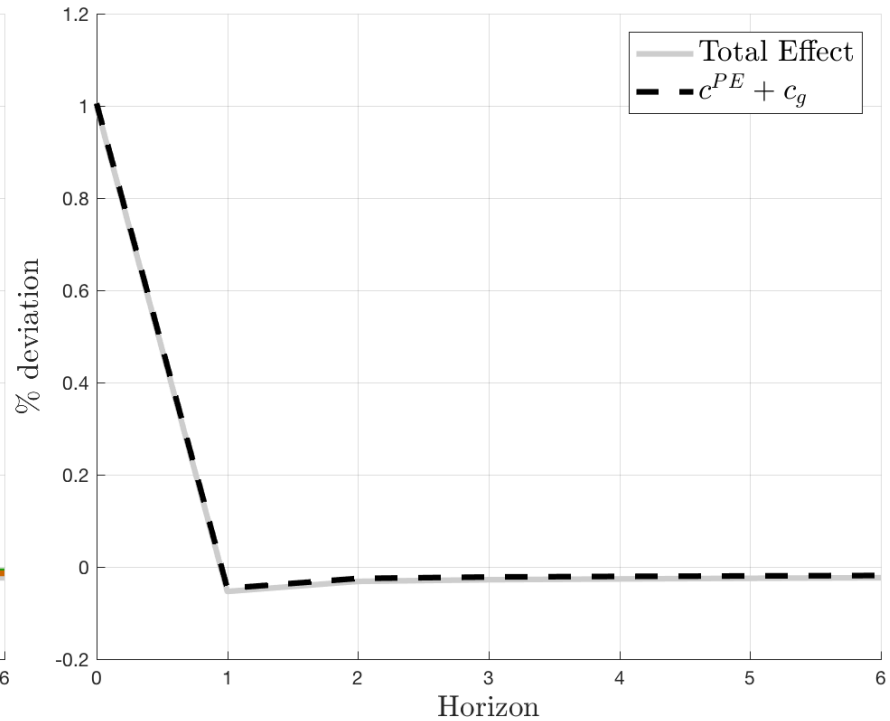
- Approx. demand equivalence: A2 holds, A1 *nearly* satisfied

  → Note: approximation deteriorates for extremely persistent private demand shocks

back

Redistribution Shock in Koby & Wolf (2019)

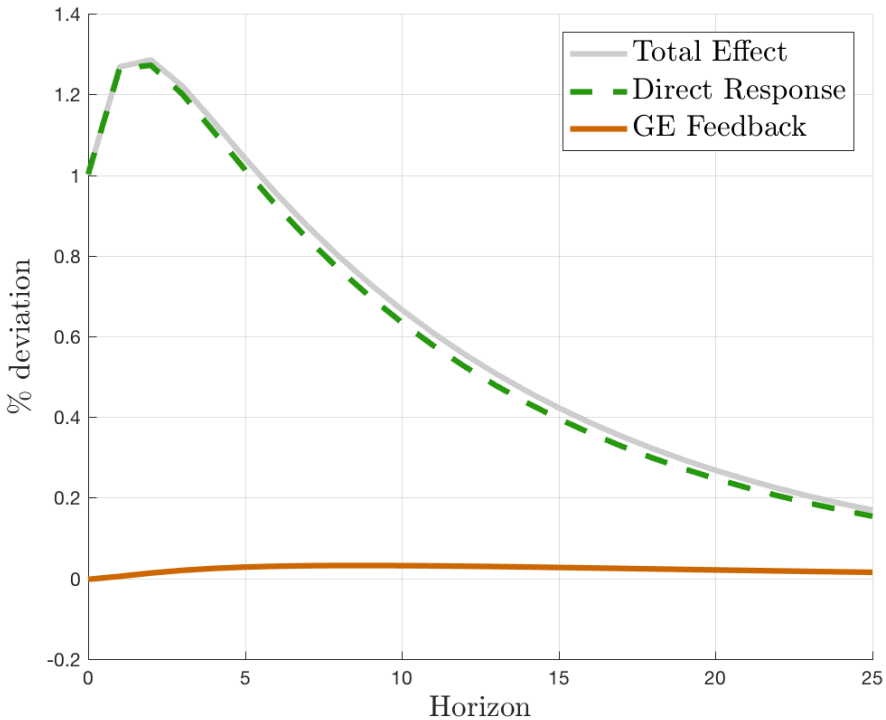


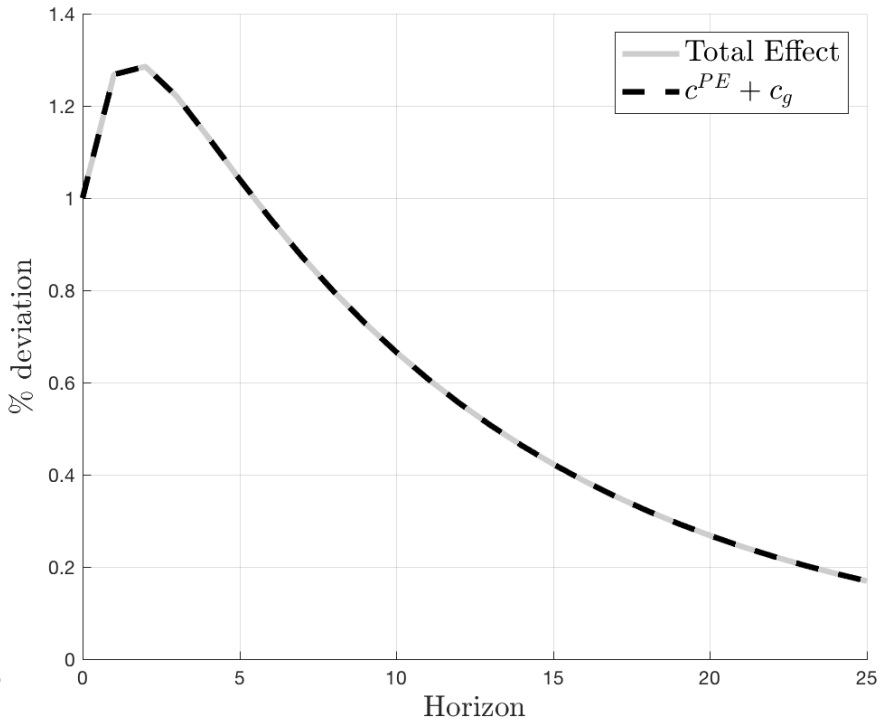


- Model environment
  - Solve model of Koby and Wolf (2019) at benchmark parameterization
  - Study *c* response to redistribution shock using demand equivalence
- Find: identical GE amplification for both shocks

▸ back

Impatience Shock in SGU (2012)





- Model environment
  - Solve model of Schmitt-Grohé & Uribe (2012) at posterior mode
  - Study *c* response to impatience shock using demand equivalence
- Find: weak crowding-in for both *b* and *g* shock

back

IKC Approximation

- Alternative approximation: intertemporal Keynesian cross
  - If no capital, rigid prices, fixed r [Auclert et al. (2018)]:

$$\mathbf{D} = \mathcal{M} \times (I - \mathcal{M})^{-1}$$

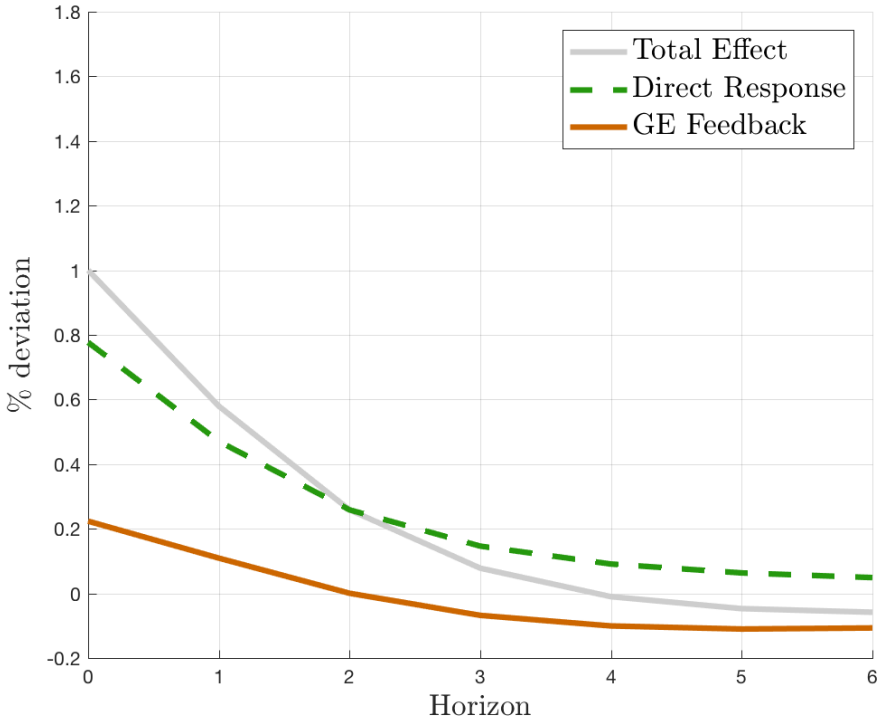
    where $\mathcal{M}$ collects *intertemporal* household MPCs
  - Can implement this in benchmark model:

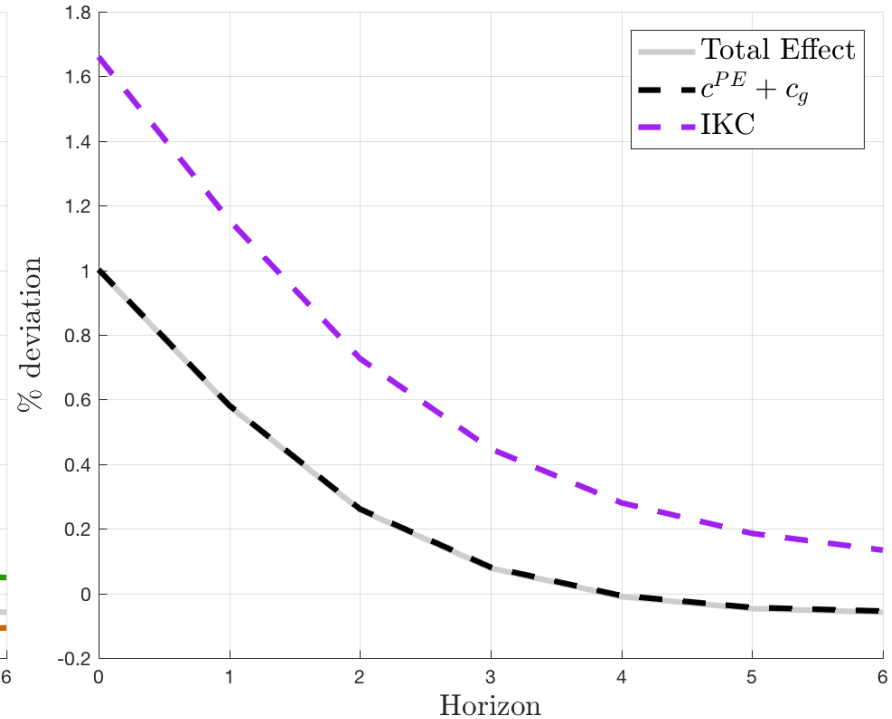
$$\begin{aligned} dC &= \mathcal{M} \times dT + \mathcal{M} \times dY \\ &= \mathcal{M} \times dT + \mathcal{M} \times (I - \mathcal{M})^{-1} \times \mathcal{M} \times dT \end{aligned}$$

- Find: GE amplification is overstated by around 40%

$\Rightarrow$ **Trade-off**: model scope vs. macro info requirements

IKC Approximation





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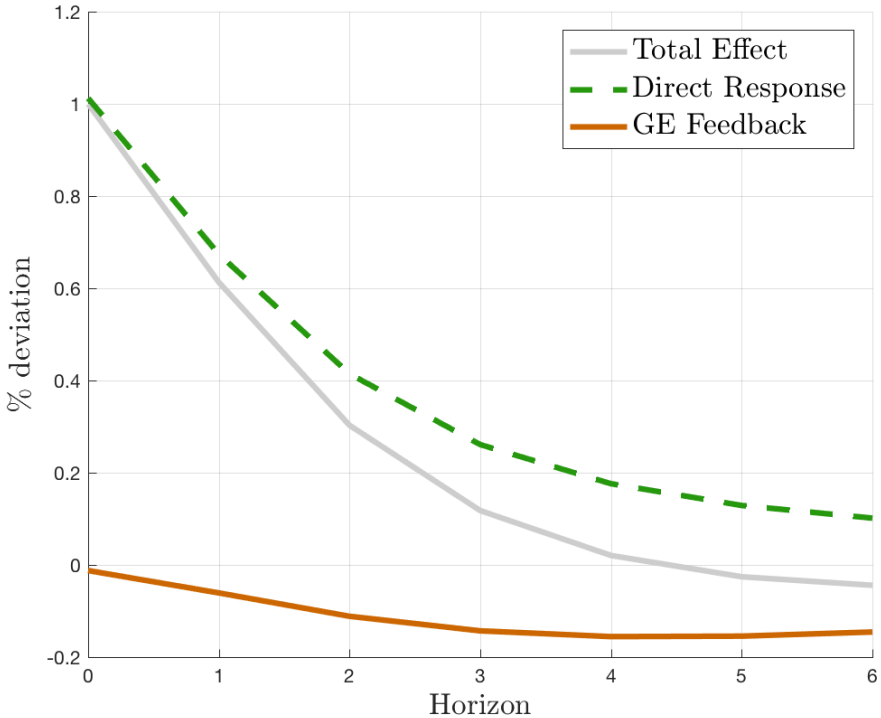
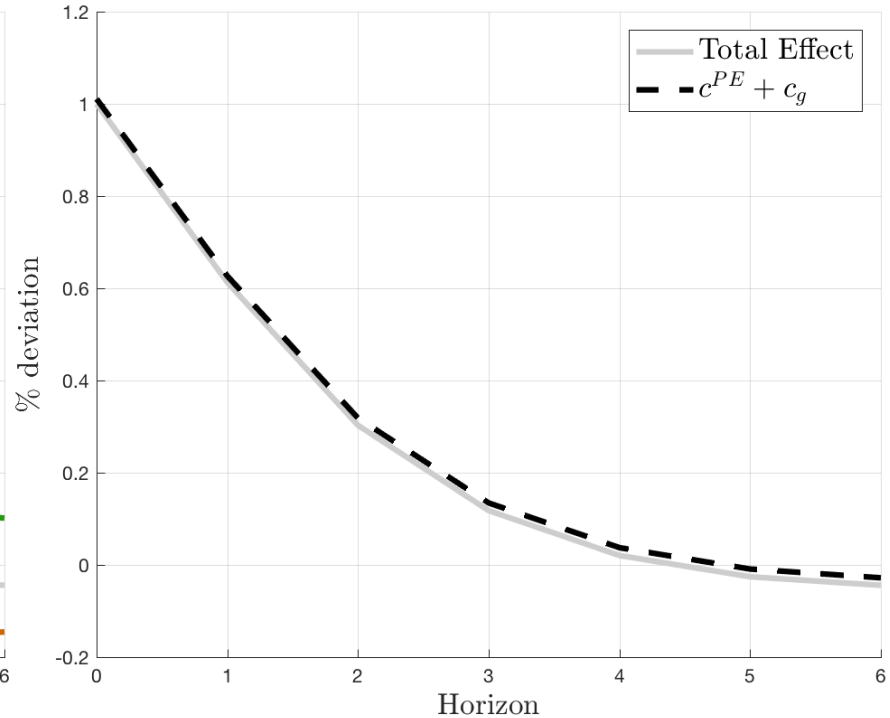
Two-Asset Model





- Model environment
  - Two-asset HANK model with random Calvo access to illiquid asset
  - Study *c* response to income tax rebate using demand equivalence
- Find: even smaller error since offsetting bias

back

Model Generalizations

1. Durable & non-durable consumption ▸ Details
   - Obtain exact demand equivalence if perfectly substitutable in production
2. Behavioral models: exact equivalence in Molavi (2019)
3. Richer portfolio choice: limited rebalancing ▸ Details
4. Multi-sector models ▸ Details
   - Small estimated relative price effects
   - Het. incidence: extra feedback since gov't spending disproportionately on (high-skill) labor-intensive goods, but quantitatively negligible
   - C vs. I: only matters with high price elasticity of I + strong wealth effects
5. Valued & productive G ▸ Details
   - Exact equivalence in special cases, approx. equivalence at empirical estimates of complementarity & productivity

▸ back

Durables & Non-Durables

- Generalized consumption-saving problem:

$$\max \quad \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta_i^t e^{\varepsilon_t^b} u(c_{it}, d_{it}^h, \ell_{it}) \right]$$

such that

$$c_{it} + d_{it} + a_{it} + b_{it} = (1 - \tau_\ell) w_t \ell_{it} e_{it} + \tau_{it} + \frac{1 + i_{t-1}^b(b_{it-1})}{1 + \pi_t} b_{it-1} + \frac{1 + i_{t-1}^a}{1 + \pi_t} a_{it-1} + \phi_a(a_{it}, a_{it-1}) + (1 - \delta) d_{it-1}^h + \phi_d(d_{it}^h, d_{it-1}^h)$$

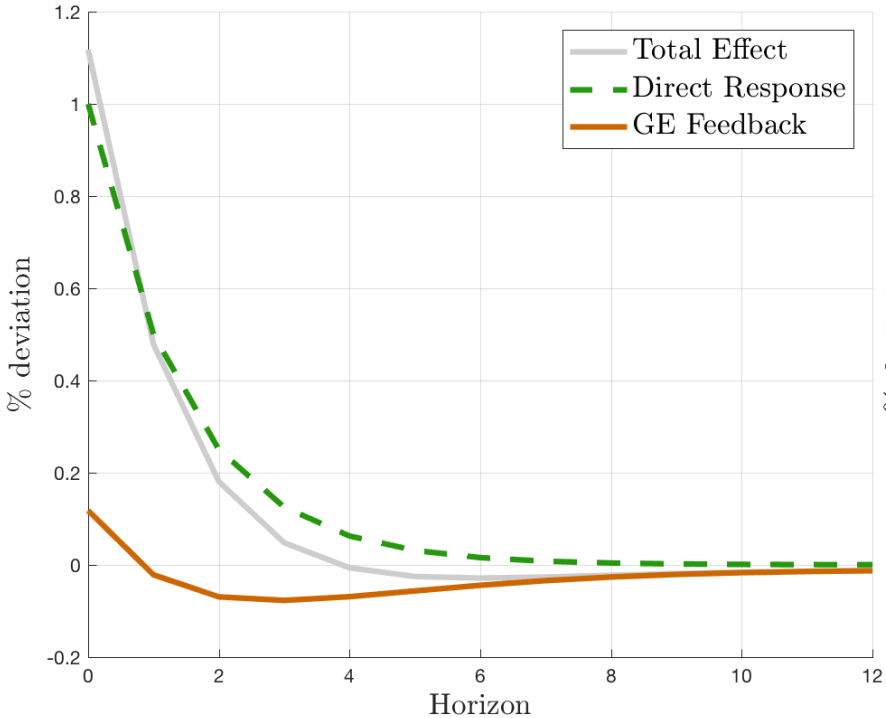
- Main result: with aggregate resource constraint

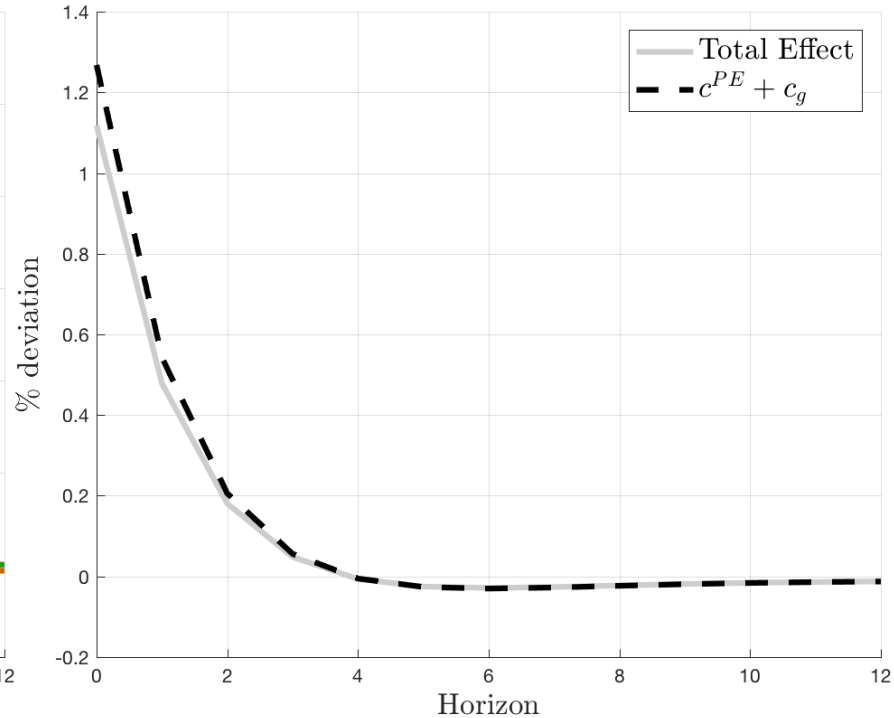
$$y_t = \underbrace{c_t + d_t^h - (1 - \delta) d_t^h}_{e_t} + i_t + g_t$$

still obtain generalized demand equivalence for e_t

back

Valued G





- Model environment
  - Estimated HANK model + private and public consumption are complements [Leeper et al. (2017)]
  - Study *c* response to impatience shock using demand equivalence
- Find: upward bias since *c* ↑ due to *g* ↑ (complements)

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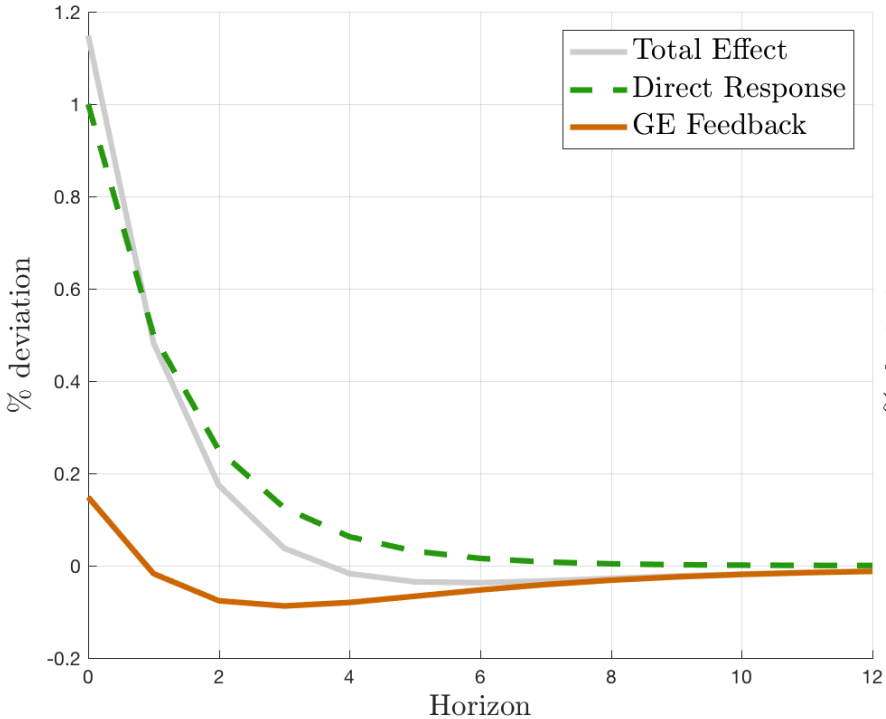
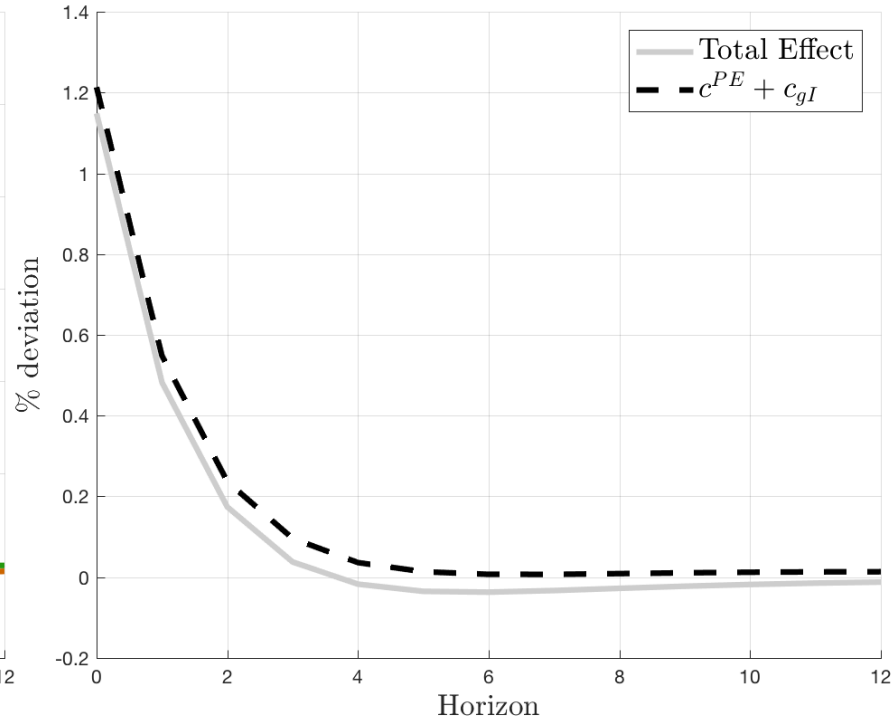
Productive G





- Model environment
  - Estimated HANK model + public investment is productive [Leeper et al. (2010)]
  - Study *c* response to impatience shock using investment *g* expansion
- Find: upward bias due to productive benefits of *g* expansion

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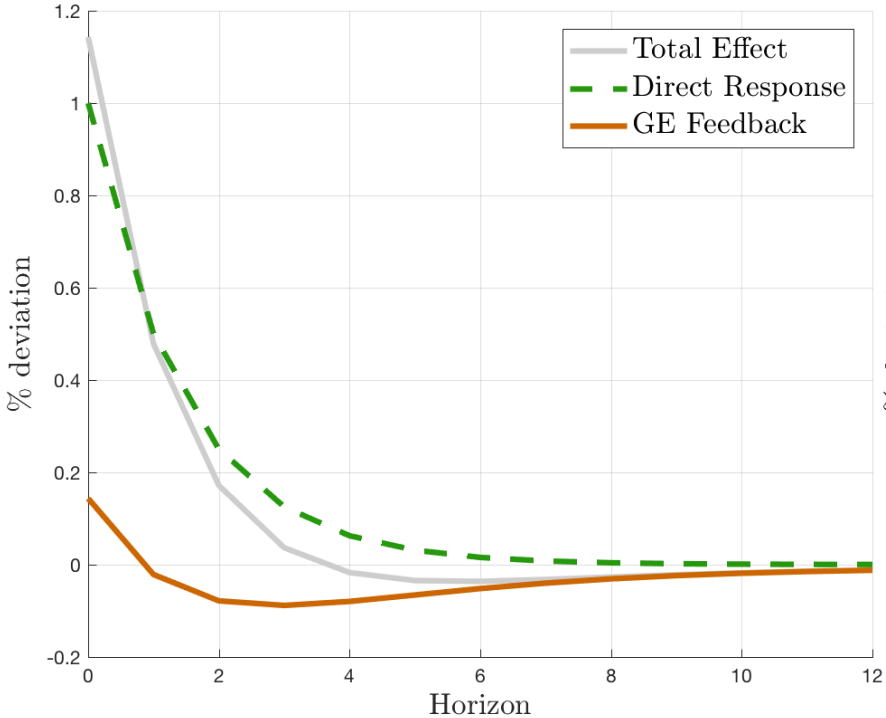
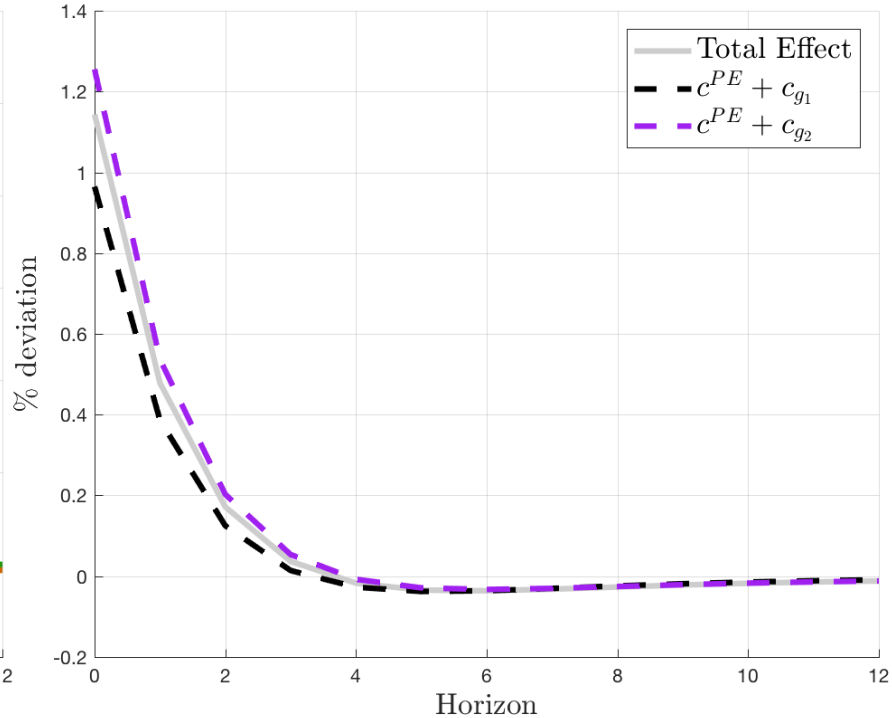
Incidence: Labor Share





- Model: 3-sector, spender-saver variant of HANK model
  - Calibration: labor shares match average network-adjusted labor shares [Baqaee (2018)]
  - Study *c* response to impatience shock using investment *g* expansion
- Find: upward bias for high labor share, downward bias for low labor share
  - Note: probably over-state inaccuracy since *g* has high *skilled* labor share

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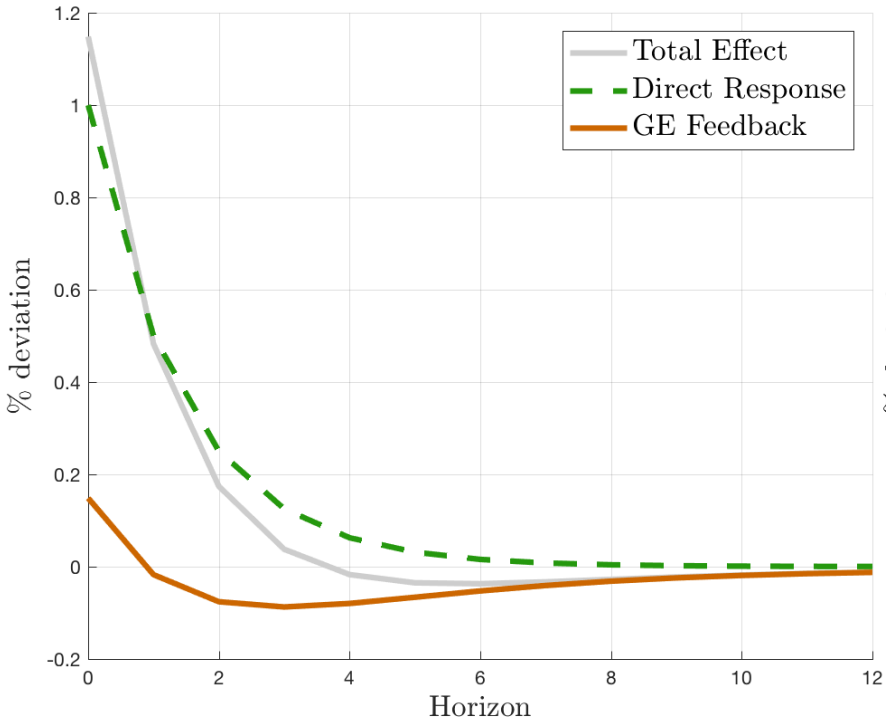
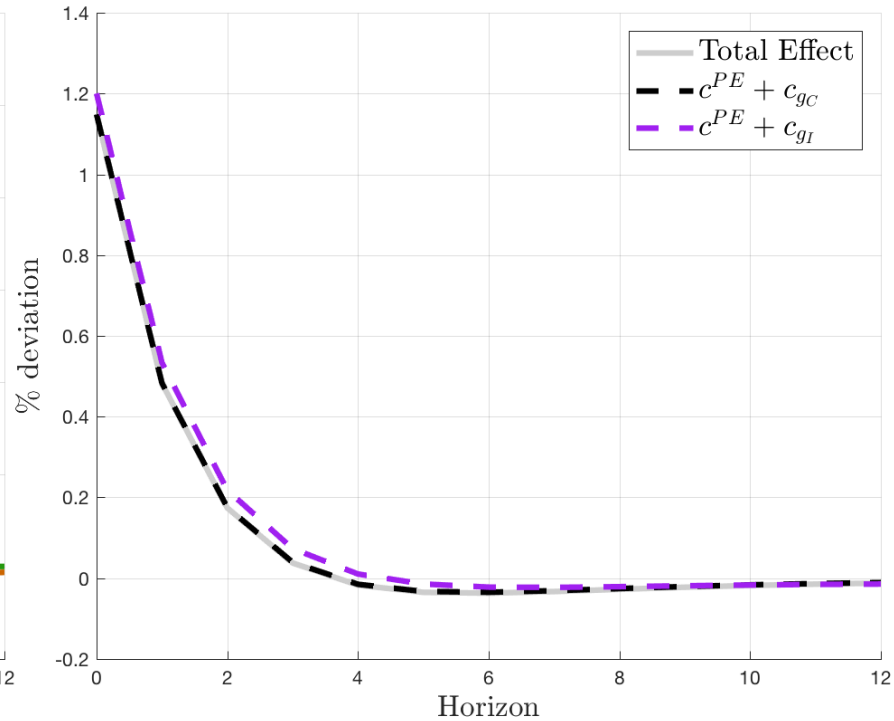
Investment vs. Consumption





- Model: symmetric 2-sector variant of HANK model
  - Restrict flow of productive factors across sectors [Boehm (2018)]
  - Study c response to impatience shock using investment g expansion
- Find: g_c is accurate, multipliers for g_i less persistent

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Relative Price Responses

- Evidence on relative price responses
  - Ramey-Shapiro: 2.5% price response for shock moving GDP by 4%
  - Nakamura-Steinsson, own calculations: small response
- What happens in a model consistent with RS responses?
  - Model: immobile labor, sector-specific capital, moderately sticky prices (reset probability $\approx$ 60%)
  - Result: additive decomposition over-states by $\approx$ 5%
- Indirect evidence: almost identical results for federal spending and military spending forecast errors

SVAR Analysis: Details

- Data and model set-up
  - Variables: forecast news, gov't spending, output, consumption, investment, hours worked, tax measure, (aggregate deficit)
  - Specification: four lags, quadratic trend, standard prior on orthogonal reduced-form parameterization
  - Sample: 1981Q2 - 2007Q4 (forecast data availability, stable MP rule)
- Shock identification
  - Formal ID assumption: forecast errors z_t satisfy

$$z_t = \sum_{\ell=1}^{\infty} (\Psi_\ell z_{t-\ell} + \Lambda_\ell y_{t-\ell}) + \alpha \varepsilon_t^g + \sigma_\nu \nu_t$$

  - Implementation: order first in recursive SVAR
- Robustness: more lags, earlier sample, more variables (e.g. hours, business income, non-durable consumption)

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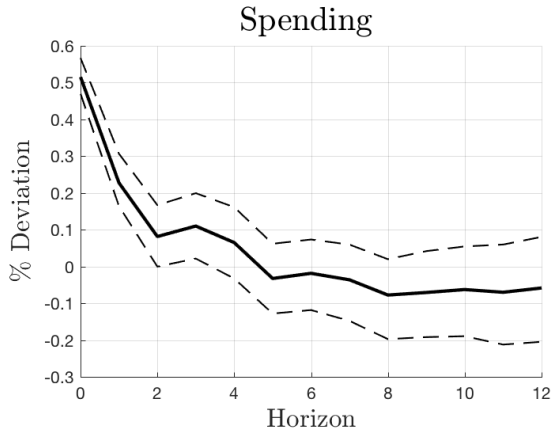
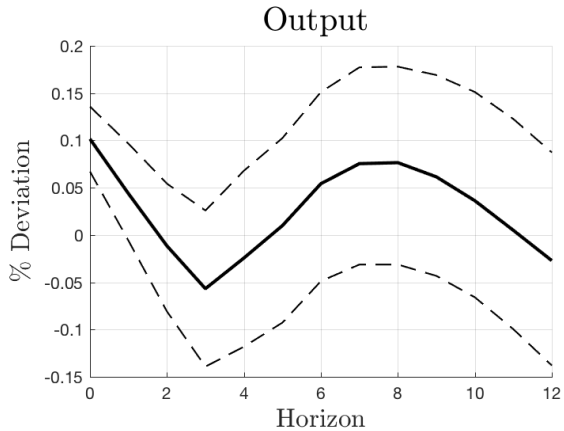
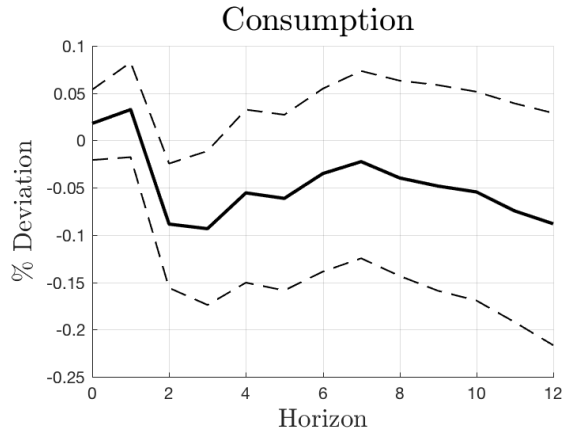
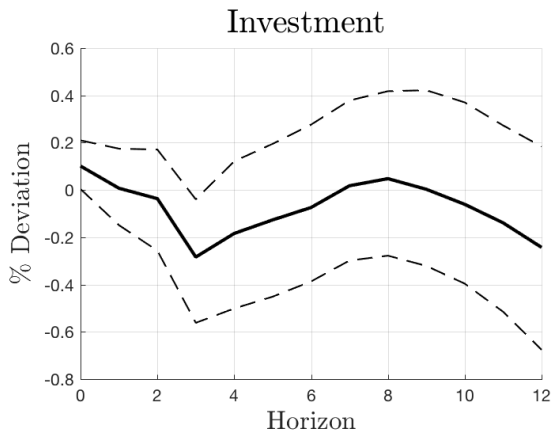
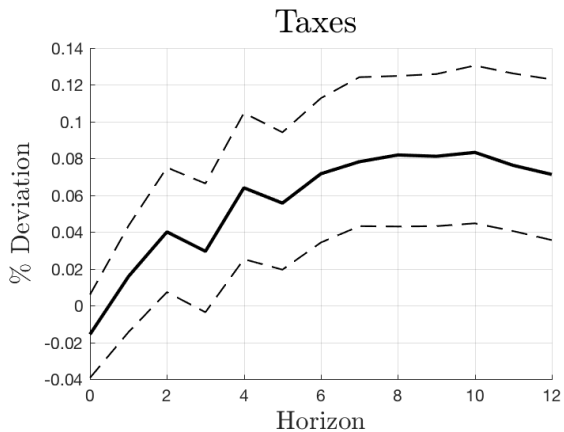
SVAR Analysis: Details

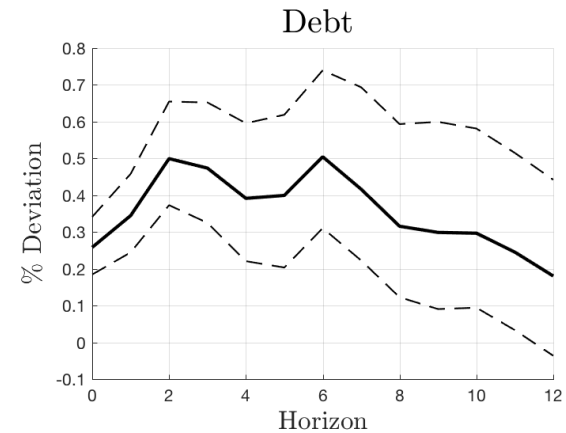












Investment Demand Equivalence

- Need slightly different assumptions for demand equivalence:

  A1 Labor is indivisible or fully demand-determined.

  A2 Households face no idiosyncratic earnings risk, no borrowing wedge, and adjustments in share holdings incur no incremental costs.

  A3 The monetary authority only responds to inflation and the output *gap*.

Proposition

Consider investment tax stimulus and government spending shocks such that $\mathbf{i}_q^{PE} + \mathbf{y}_q^{PE} = \mathbf{g}^{PE}$*. Under A1-A3, aggregate investment impulse responses satisfy, to first order,*

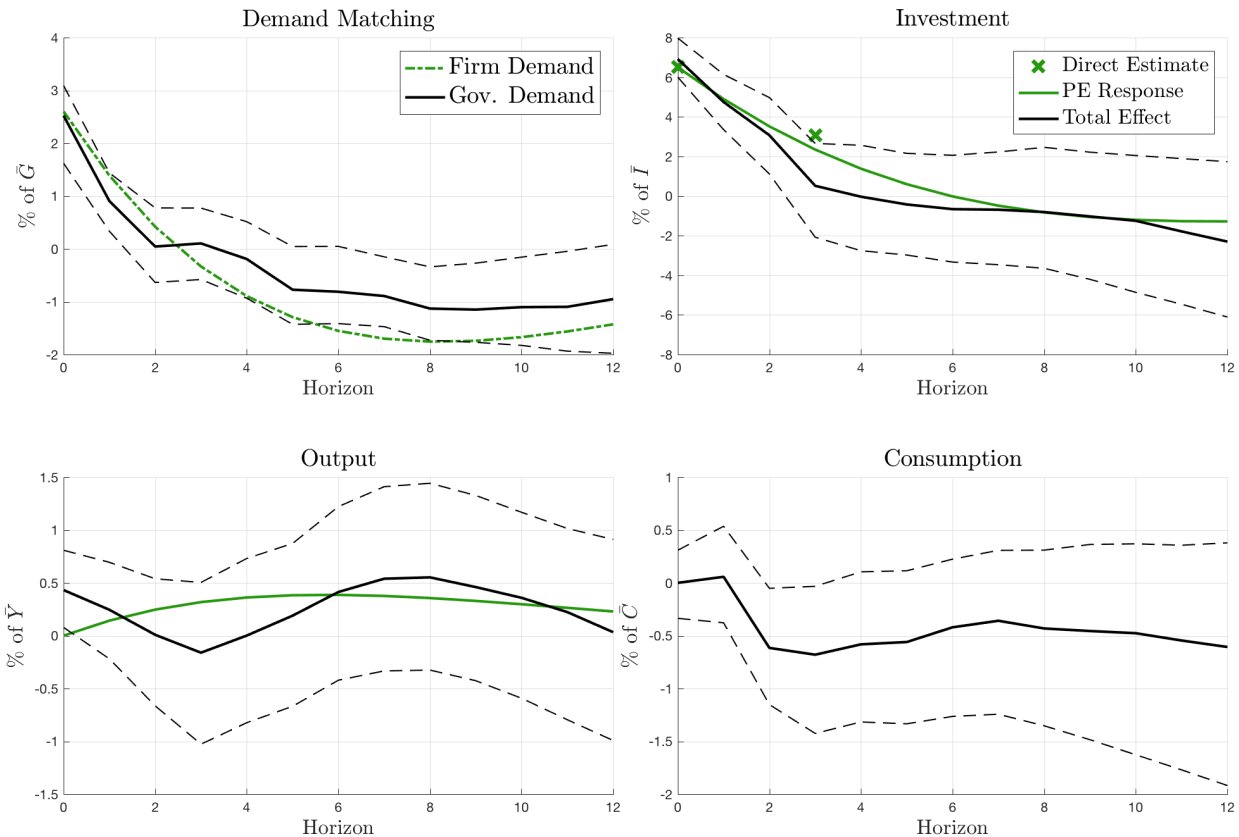
$$\mathbf{i}_q = \underbrace{\mathbf{i}_q^{PE}}_{\text{PE response}} + \underbrace{\mathbf{i}_g}_{\text{GE feedback}}$$

- Satisfy exactly in most quantitative heterogeneous-firm models

  [Khan & Thomas (2008, 2013), Winberry (2019), Ottonello & Winberry (2019)]

Application: Investment Tax Credit

- Study effects of bonus depreciation [Zwick & Mahon (2017)]
  - Match investment response path identified from micro quasi-experiment
  - Map into path $\mathbf{y}^{PE}$ using simple PE model of investment
- Main result: accommodation through $y \uparrow$, not $c \downarrow$



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Cross-Regional Regressions

- Companion note extends methodology to regional regressions:

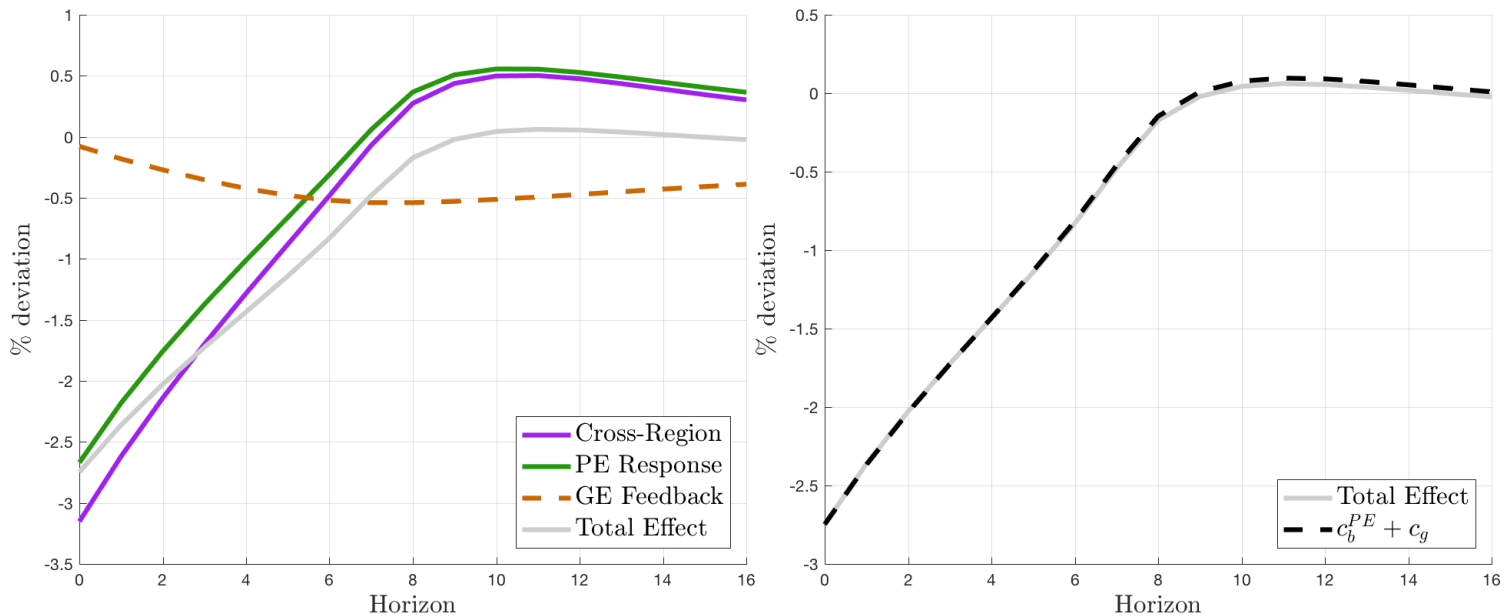
$$c_{kt+h} = \alpha_k + \delta_t + \beta_{h,b}\varepsilon_{kt,b_k} + u_{kt+h}$$

- How to interpret $\beta_{h,b}$?
  - Equal to IRF of region-k consumption to region-k demand shock ε_b
  - $\neq$ macro IRF due to presence of local GE + absence of aggregate GE

- How to map $\beta_{h,b}$ into macro counterfactuals?
  - Strip out local GE by subtracting $\mathbf{c}_{k,g_k}$ (IRF of local c to local g)
  - Regional invariance: aggregate as $\int_0^1 \mathbf{c}^{PE}_{k,b_k}$, then treat as one-region economy & aggregate through $\mathbf{c}_g$

Application: Household Deleveraging

- Back-of-envelope calculation for Mian-Sufi household deleveraging:
  1. Aggregating cross-regional estimates implies consumption drop of 3%
  2. Mapping to pure PE effect through $\mathbf{c}_{k,g_k}$: $\approx$ 2.6% decline
  3. Mapping into aggregate IRF through $\mathbf{c}_g$: $\approx$ 2.6% decline
- Macro counterfactual in model consistent with $\beta_{h,b}$, $\mathbf{c}_{k,g_k}$ & $\mathbf{c}_g$:



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