Monetary Policy in an Open Economy with Production Networks

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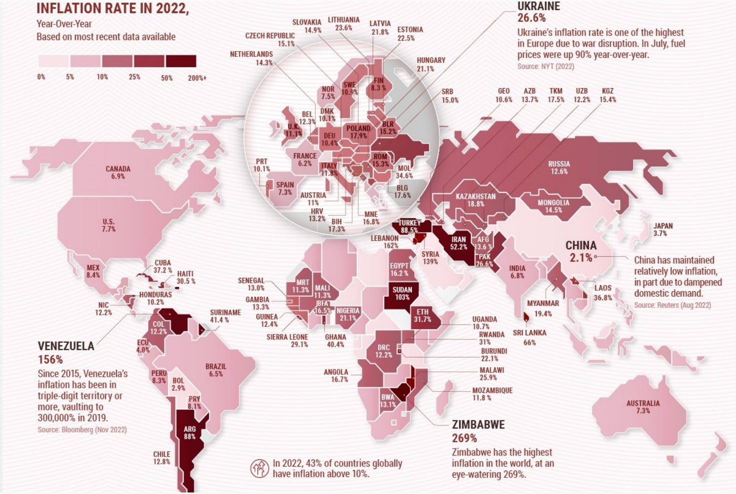
Motivation: Global Inflation



- Once again, a wave of inflation spreading across the interconnected world
- https://www.visualcapitalist.com/

Question: Monetary Policy Design

Research Question

- How shall an economy design its monetary policy in such a world?

Closed Economy

- 100% of the output $\rightarrow$ input-output linkages $\rightarrow$ domestic final demand
- 100% of the input $\leftarrow$ input-output linkages $\leftarrow$ use of domestic factor

$\implies$ output gap due to sectoral inflation $\propto$ sectoral sales
(La'O and Tahbaz-Salehi, 2022; Rubbo, 2023)

Open Economy

e.g. manufacture of computer, electronic and optical products in Mexico

- $< 1/10$ of the output $\rightarrow$ input-output linkages $\rightarrow$ domestic final demand
- $< 1/3$ of the input $\leftarrow$ input-output linkages $\leftarrow$ use of domestic factor

$\implies$ output gap due to sectoral inflation $\propto$???

Our Approach

- small open economy + production networks + nominal rigidity

Answer: A Formula to Implement OG Policy

Output gap stabilizing monetary policy (OG policy) can be implemented
by targeting a **weighted sectoral inflation index**.

A sector is assigned a **smaller weight** if it is
smaller in sales (conventional wisdom in closed economy) or
more like "export processing" (import material and export product)

OG policy is nearly optimal quantitatively, and
ignoring openness induces too much economic contraction
when fighting inflation driven by foreign price shocks.

Roadmap

Model: SOE with Production Networks

Result: OG Inflation Index

Implication: Welfare Comparison

SOE with Production Networks

Environment

- A static economy with N sectors index by $i \in \{1, 2, \cdots, N\}$
- Two types of producers in each sector i:
  1. monopolistically-competitive firms $f \in [0, 1]$:
     labor + intermediate inputs $\rightarrow$ differentiated goods
  2. competitive goods packer (modeling device):
     differentiated goods $\rightarrow$ composite sectoral product
- Supply of composite sectoral product $\rightarrow$
  1. intermediate inputs
  2. consumption
  3. export
- Import of composite sectoral product $\rightarrow$
  1. intermediate inputs
  2. consumption
- Consumption $\rightarrow$ representative households $\rightarrow$ labor

Firms

- Monopolistically-competitive firm $f \in [0,1]$ in sector i with **CRS technology**

$$Y_{if} = A_i \cdot F_i(L_{if}, \{X_{Hif,Hj}, X_{Hif,Fj}\}_j)$$

- **Costs of inputs** given import prices $\{P^*_{IM,Fj}\}_j$ and nominal exchange rate S

$$TC_{if} = WL_{if} + \sum_{j=1}^{N}(P_j X_{Hif,Hj} + S \cdot P^*_{IM,Fj} X_{Hif,Fj})$$

- Cost minimization given $Y_{if} \to$ **marginal cost of production** MC_i

- **Nominal profit** of firm f in sector i with sales tax $\{\tau_i\}_i$

$$\Pi_{if} = (1-\tau_i)P_{if}Y_{if} - MC_i \cdot Y_{if}$$

Nominal Rigidities

- Competitive goods packer, sectoral price, and **demand function**

$$Y_i = \left(\int_0^1 Y_{if}^{\frac{\varepsilon_i - 1}{\varepsilon_i}} df \right)^{\frac{\varepsilon_i}{\varepsilon_i - 1}} \implies P_i = \left(\int_0^1 P_{if}^{\frac{1-\varepsilon_i}{d}} f \right)^{\frac{1}{1-\varepsilon_i}}, \quad Y_{if} = \left(\frac{P_{if}}{Pi} \right)^{-\varepsilon_i} Y_i$$

- **Desired price** that maximizes Π_{if} subject to the demand function

$$P_i^{\#} = \frac{1}{1-\tau_i} \frac{\varepsilon_i}{\varepsilon_i - 1} MC_i$$

- **Calvo pricing**
  $f \geq \delta_i \in [0,1]$: choosing $P_i^{\#}$
  $f < \delta_i \in [0,1]$: no price adjustment

Households

- Representative households' **preference**

$$U\left(\mathcal{C}(\{C_{Hi}, C_{Fi}\}_i), L\right) = \frac{\mathcal{C}(\{C_{Hi}, C_{Fi}\}_i)^{1-\sigma}}{1-\sigma} - \frac{L^{1+\varphi}}{1+\varphi}$$

- **Budget** constraint with lump-sum transfer T

$$\sum_{i=1}^{N}(P_i C_{Hi} + S \cdot P^*_{IM,Fi} C_{Fi}) \leq WL + \sum_{i=1}^{N} \int_0^1 \Pi_{if} df + T$$

- **Money demand** for medium of exchange

$$M_d = \sum_{i=1}^{N}(P_i C_{Hi} + S \cdot P^*_{IM,Fi} C_{Fi})$$

Export

- **No arbitrage** between export (after-tax) and domestic prices

$$(1 - \tau_{EX,i})P_{EX,i} = P_i$$

- Simple **export demand** function

$$Y_{EX,i} = \left(\frac{P_{EX,i}}{S \cdot P^*_{EX,Fi}} \right)^{-\theta_{Fi}} D^*_{EX,i}$$

with given foreign competing prices $P^*_{EX,Fi}$ and strength of demand $D^*_{EX,i}$

Government

- Fiscal budget balance under non-contingent **tax rates** $\{\tau_i, \tau_{EX,i}\}_i$

$$T = \sum_{i=1}^{N} \left(\tau_i \int_0^1 P_{if} Y_{if} df + \tau_{EX,i} P_{EX,i} Y_{EX,i} \right)$$

- State-contingent **money supply** $M(\xi)$ conditional on aggregate shocks

$$\xi = \left\{ A_i, P^*_{IM,Fi}, P^*_{EX,Fi} \right\}_{i \in \{1,2,\ldots,N\}} \in \Xi = \mathbb{R}^{3N}_{\geq 0}$$

Market Clearing

- **Product**

$$Y_i(\xi) = C_{Hi}(\xi) + \sum_{i=1}^{N} \int_0^1 X_{Hjf,Hi}(\xi) df + Y_{EX,i}(\xi)$$

- **Labor**

$$L(\xi) = \sum_{i=1}^{N} \int_0^1 L_{if}(\xi) df$$

- **Money**

$$M(\xi) = M_d(\xi)$$

Efficient Flexible Price Economy

- $\tau_i = -\frac{1}{\varepsilon_i - 1}$ removes monopoly distortion in domestic market
- $\tau_{EX,i} = \frac{1}{\theta_{Fi}}$ profits from monopoly power in foreign market
- Flexible price$\rightarrow$ First-Best in home country
- Reference economy for welfare loss

Optimal Monetary Policy

Perturbation around efficient steady-state and flexible price equilibrium

$$\widehat{x} \equiv \ln x - \ln x^{ss} \quad \text{and} \quad \widehat{x}^{gap} \equiv \ln x - \ln x^{flex}$$

- Model implied **Phillips Curves**: output gap linked with sectoral inflation

$$\widehat{\mathbf{P}}(\boldsymbol{\xi}) = \boldsymbol{\mathcal{B}}\widehat{C}^{gap}(\boldsymbol{\xi}) + \boldsymbol{\mathcal{V}}\widehat{\boldsymbol{\xi}} + o(||\widehat{\boldsymbol{\xi}}||)$$

- Model implied **welfare loss**: output gap v.s. sectoral inflation

$$U^{gap}(\boldsymbol{\xi}) \propto -\frac{1}{2}\widehat{C}^{gap}(\boldsymbol{\xi})^2 - \frac{1}{2}\widehat{\mathbf{P}}(\boldsymbol{\xi})^\top \boldsymbol{\mathcal{L}}\widehat{\mathbf{P}}(\boldsymbol{\xi}) + o(||\widehat{\boldsymbol{\xi}}||^2)$$

- **Money supply** $M(\boldsymbol{\xi}) \implies$ output gap $\widehat{C}^{gap}(\boldsymbol{\xi})$ and sectoral inflation $\widehat{\mathbf{P}}(\boldsymbol{\xi})$

Choose $\widehat{C}^{gap}(\boldsymbol{\xi})$ and $\widehat{\mathbf{P}}(\boldsymbol{\xi})$ to minimize welfare loss s.t. Phillips Curve

Focusing on Output Gap

$$U^{gap}(\xi) \propto -\frac{1}{2}\widehat{C}^{gap}(\xi)^2 - \frac{1}{2}\mathcal{B}^\top \mathcal{L}\mathcal{B} \cdot \widehat{C}^{gap}(\xi)^2 - (\mathcal{V}\widehat{\xi})^\top \mathcal{L}\mathcal{B} \cdot \widehat{C}^{gap}(\xi) - \frac{1}{2}(\mathcal{V}\widehat{\xi})^\top \mathcal{L}(\mathcal{V}\widehat{\xi}) + o(||\widehat{\xi}||^2)$$

- $\mathcal{B}^\top \mathcal{L}\mathcal{B}$: output gap $\rightarrow$ sectoral inflation $\rightarrow$ welfare loss
- $(\mathcal{V}\widehat{\xi})^\top \mathcal{L}\mathcal{B}$: interaction of output gap and shocks (quantitatively small)
- $(\mathcal{V}\widehat{\xi})^\top \mathcal{L}(\mathcal{V}\widehat{\xi})$: policy-irrelevant term

It is innocuous to focus on output gap stabilizing policy (**OG policy**), which removes unobservable output gap by stabilizing observable inflation index.

OG Inflation Index

Roadmap

Open Economy Production Networks: defining centralities

Characterizing the OG Weights: using centralities

Comparing with Closed Economy: new results

Constructing OG Inflation Index: summary

Open Economy Production Networks: Production

Production

$$F_i(L_{if}, \{X_{Hif,Hj}, X_{Hif,Fj}\}_j)$$
$$= \alpha_i^{-\alpha_i} \prod_{j=1}^{N} \omega_{i,j}^{-\omega_{i,j}} \cdot L_{if}^{\alpha_i} \prod_{j=1}^{N} \left(v_{x,i,j}^{\frac{1}{\theta_j}} X_{Hif,Hj}^{\frac{\theta_j - 1}{\theta_j}} + (1 - v_{x,i,j})^{\frac{1}{\theta_j}} X_{Hif,Fj}^{\frac{\theta_j - 1}{\theta_j}} \right)^{\frac{\theta_j}{\theta_j - 1} \cdot \omega_{i,j}}$$

- α_i: labor share
- $\omega_{i,j}$: intermediate input share ($\alpha_i + \sum_{j=1}^{N} \omega_{i,j} = 1$)
- $v_{x,i,j}$: home bias of intermediate input demand

Open Economy Production Networks: Customer Centrality

Define **Customer Centrality** $\widetilde{\alpha}_i$ as

$$\widetilde{\alpha}_i = \alpha_i + \sum_{j=1}^{N} \omega_{i,j} v_{x,i,j} \widetilde{\alpha}_j$$

Interpretation 1: use of labor by sector i as a customer, either directly, or indirectly through other sectors whom sector i purchases inputs from

Interpretation 2: absorbing all use of labor from upstream sectors

Closed Economy: $\widetilde{\alpha}_i = 1$

Open Economy Production Networks: Consumption

Consumption

$$\mathcal{C}(\{C_{Hi}, C_{Fi}\}_i) = \prod_{i=1}^{N} \beta_i^{-\beta_i} \cdot \prod_{i=1}^{N} \left(v_i^{\frac{1}{\theta_i}} C_{Hi}^{\frac{\theta_i - 1}{\theta_i}} + (1 - v_i)^{\frac{1}{\theta_i}} C_{Fi}^{\frac{\theta_i - 1}{\theta_i}} \right)^{\beta_i}$$

$$P_C = \prod_{i=1}^{N} \left(v_i P_i^{1-\theta_i} + (1 - v_i)(S \cdot P^*_{IM,Fi})^{1-\theta_i} \right)^{\frac{\beta_i}{1-\theta_i}}$$

- β_i: consumption basket share ($\sum_{j=1}^{N} \beta_i = 1$)
- v_i: home bias of consumption demand
- θ_i: home-foreign elasticity of substitution

Open Economy Production Networks: Supplier Centrality

Define **Supplier Centrality** $\widetilde{\beta}_i$ as

$$\widetilde{\beta}_i = \beta_i v_i + \sum_{j=1}^{N} \widetilde{\beta}_j \omega_{j,i} v_{x,j,i}$$

Interpretation 1: contribution of sector i as a supplier to final consumption, either directly, or indirectly through other sectors who use i's products

Interpretation 2: absorbing all cost towards CPI via downstream sectors

Closed Economy: $\widetilde{\beta}_i = \lambda_i^{ss}$ (steady-state sales-to-GDP ratio)

Open Economy Production Networks: Net Export

Net Export

- Sales and export ratios:

$$\lambda_i \equiv \frac{P_i Y_i}{P_C C} \quad \text{and} \quad \lambda_{EX,i} \equiv \frac{P_{EX,i} Y_{EX,i}}{P_C C}$$

- Net export elasticity w.r.t. sectoral prices

$$\rho_{NX,i} = (\theta_{Fi} - 1)\lambda_{EX,i}^{ss} + (\theta_i - 1)\left[\beta_i v_i (1 - v_i) + \sum_{j=1}^{N} \lambda_j^{ss} \omega_{j,i} v_{x,j,i} (1 - v_{x,j,i})\right]$$

3 parts: export + domestic demand for final goods + intermediate inputs
Interpretation: $P_i \downarrow$ by $1\% \rightarrow NX_i \uparrow \rightarrow \frac{NX\uparrow}{GDP^{ss}}$ by $\rho_{NX,i}\%$

Open Economy Production Networks: Net Export Centrality

Define **Net Export Centrality** $\widetilde{\rho}_{NX,i}$ as

$$\widetilde{\rho}_{NX,i} = \rho_{NX,i}\widetilde{\alpha}_i + \sum_{j=1}^{N} \widetilde{\rho}_{NX,j}\omega_{j,i}v_{x,j,i}$$

Interpretation 1: $P_i \rightarrow$ other sector's prices $\rightarrow$ NX $\rightarrow$ use of labor

Interpretation 2: absorbing responses of net export driven use of labor via downstream sectors

Closed Economy: $\widetilde{\rho}_{NX,i} = 0$

Open Economy Production Networks: Vertical Economy

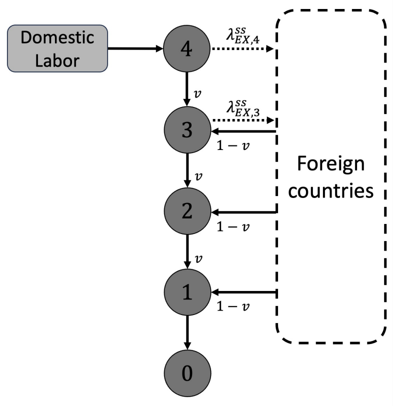


Figure 1: Vertical Economy Example

Supplier Centrality

$$(\widetilde{\beta}_1, \widetilde{\beta}_2, \widetilde{\beta}_3, \widetilde{\beta}_4) = (1, v, v^2, v^3)$$

Customer Centrality

$$(\widetilde{\alpha}_1, \widetilde{\alpha}_2, \widetilde{\alpha}_3, \widetilde{\alpha}_4) = (v^3, v^2, v, 1)$$

Net Export Centrality

$$\widetilde{\rho}_{NX,1} = 0$$

$$\widetilde{\rho}_{NX,2} = (\theta - 1)\left[0 + \widetilde{\beta}_2(1-v)\right]\widetilde{\alpha}_2$$

$$\widetilde{\rho}_{NX,3} = (\theta - 1)\left[\lambda^{ss}_{EX,3} + \underbrace{\widetilde{\beta}_3(1-v^2)}_{\text{leaked demand}}\right]\widetilde{\alpha}_3$$

Characterizing the OG Weights: Main Results

Theorem (OG weights)

$$\widehat{C}^{gap} \propto -\sum_{i=1}^{N} \mathcal{M}_{OG,i} \cdot \underbrace{(\widehat{P}_i - \widehat{P}_i^{\#})}_{\text{markup wedge}} + o(||\widehat{\xi}||)$$

$$\mathcal{M}_{OG,i} = \underbrace{\widetilde{\beta}_i}_{\mathcal{M}_{OG,1}} + \underbrace{\kappa \cdot \widetilde{\rho}_{NX,i}}_{\mathcal{M}_{OG,2}} + \underbrace{\kappa \cdot (\lambda_i^{ss}\widetilde{\alpha}_i - \widetilde{\beta}_i)}_{\mathcal{M}_{OG,3}}$$

- $\widetilde{\beta}_i$: markup $\downarrow$ (CPI $\downarrow$) $\Longrightarrow$ real wage $\uparrow$ $\Longrightarrow$ supply of labor $\uparrow$ (conventional)
- $\widetilde{\rho}_{NX,i}$: markup $\downarrow$ ($\frac{home}{foreign}$ price $\downarrow$) $\Longrightarrow$ net export $\uparrow$ $\Longrightarrow$ use of labor $\uparrow$
- $\lambda_i^{ss}\widetilde{\alpha}_i - \widetilde{\beta}_i$: markup $\downarrow$ $\Longrightarrow$ labor income $\uparrow$ + profit income $\downarrow$ (negligible)
- κ: relative importance of trade ($\kappa \to 1$ from below if extremely open)

Characterizing the OG Weights: Variance Decomposition

$$1 = \frac{cov(\mathcal{M}_{OG1,i}, \mathcal{M}_{OG,i})}{var(\mathcal{M}_{OG,i})} + \frac{cov(\mathcal{M}_{OG2,i}, \mathcal{M}_{OG,i})}{var(\mathcal{M}_{OG,i})} + \frac{cov(\mathcal{M}_{OG3,i}, \mathcal{M}_{OG,i})}{var(\mathcal{M}_{OG,i})}$$

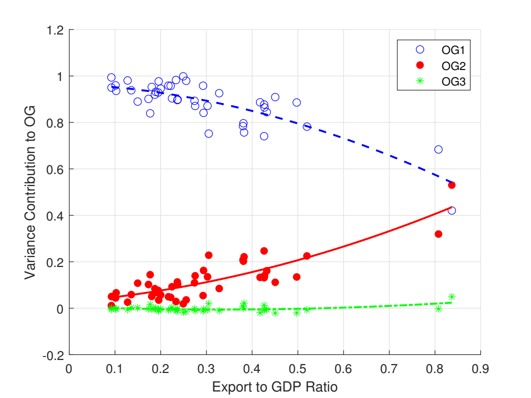


Figure 2: Variance Decomposition of $\mathcal{M}_{OG}$ in 42 Economies

Comparing with Closed Economy: Vertical Economy

- In **closed** economy,

$$\mathcal{M}_{OG,i}^{closed} = \widetilde{\beta}_i = \lambda_i^{ss}$$

- Compute the following **difference** measure

$$\frac{\mathcal{M}_{OG,i} - \mathcal{M}_{OG,i}^{closed}}{\mathcal{M}_{OG,i}^{closed}}$$

- In the **vertical** economy example,

$$\frac{\mathcal{M}_{OG,3} - \lambda_3^{ss}}{\lambda_3^{ss}} \approx \frac{\widetilde{\beta}_3 - \lambda_3^{ss}}{\lambda_3^{ss}} + \kappa \cdot \frac{\widetilde{\rho}_{NX,3}}{\lambda_3^{ss}}$$

$$= -\left(\lambda_{EX,3}^{ss}/\lambda_3^{ss}\right) + \kappa\left(\theta - 1\right)\left[v^2\left(\lambda_{EX,3}^{ss}/\lambda_3^{ss}\right) + \left(1 - v^2\right)\right]\widetilde{\alpha}_3$$

Comparing with Closed Economy: WIOD Data

Table 1: What Matters for $\frac{\mathcal{M}_{OG,i}-\lambda_i^{ss}}{\lambda_i^{ss}}$ Across Economies in WIOD

	(1)	(2)	(3)
$\lambda_{ex,i}^{ss}/\lambda_i^{ss}$	-0.623***		-0.553***
	(0.005)		(0.007)
$\widetilde{\alpha}_i$		1.083***	0.266***
		(0.0315)	(0.018)
Country FE	Yes	Yes	Yes
Obs	2,278	2,278	2,278
R^2	0.890	0.512	0.906

Comparing with Closed Economy: Mexico Case

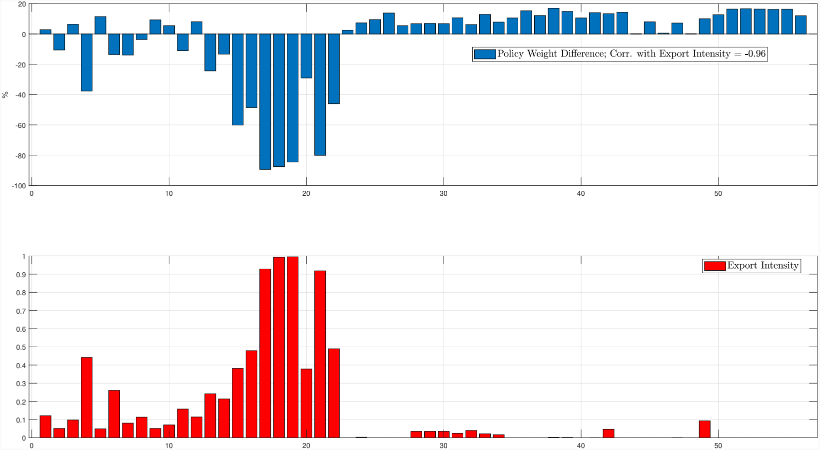


Figure 3: $\frac{\mathcal{M}_{OG,i} - \lambda_i^{ss}}{\lambda_i^{ss}}$ vs $(1 - \tau_i)\frac{\lambda_{EX,i}^{ss}}{\lambda_i^{ss}}$ across Mexico sectors

Comparing with Closed Economy: Mexico Case

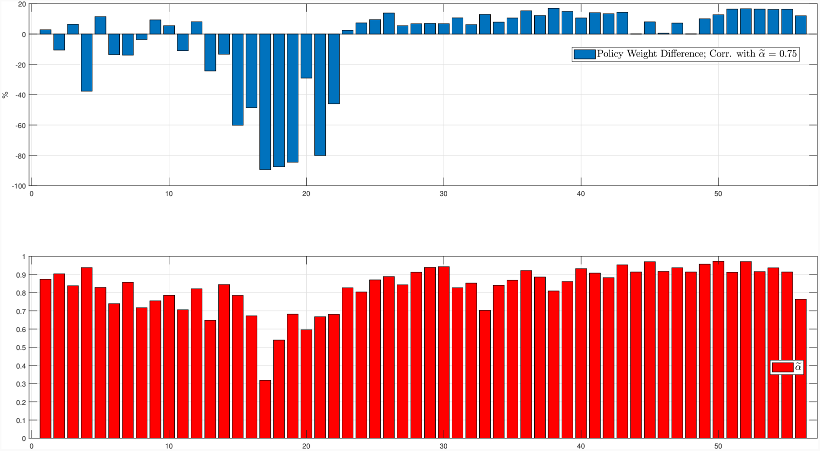


Figure 4: $\frac{\mathcal{M}_{OG,i}-\lambda_i^{ss}}{\lambda_i^{ss}}$ vs $\widetilde{\alpha}_i$ across Mexico Sectors

Comparing with Closed Economy: Mexico Case

Table 2: "Export Processing" Sectors in Mexico

ID	Sector Code	Sector Description
		......
13	C22	Manufacture of rubber and plastic products
14	C23	Manufacture of other non-metallic mineral products
15	C24	Manufacture of basic metals
16	C25	Manufacture of fabricated metal products, except machinery and equipment
17	C26	Manufacture of computer, electronic and optical products
18	C27	Manufacture of electrical equipment
19	C28	Manufacture of machinery and equipment n.e.c.
20	C29	Manufacture of motor vehicles, trailers and semi-trailers
21	C30	Manufacture of other transport equipment
22	C31_C32	Manufacture of furniture; other manufacturing
		......

Constructing OG Inflation Index

- Under static Calvo pricing,

$$\widehat{P}_i - \widehat{P}_i^{\#} = -\frac{\delta_i}{1-\delta_i}\widehat{P}_i.$$

- Define the "OG Inflation Index" as

$$\widehat{P}^{OG} = \sum_{i=1}^{N} \frac{\mathcal{M}_{OG,i}\frac{\delta_i}{1-\delta_3}}{\sum_{j=1}^{N}\mathcal{M}_{OG,j}\frac{\delta_j}{1-\delta_j}}\widehat{P}_i.$$

- $\widehat{C}^{cap}$ can be eliminated by bringing $\widehat{P}^{OG}$ to zero.

Welfare Comparison

Welfare Loss under Alternative Policies

Table 3: Ex ante Welfare Loss (% of Steady-state Consumption)

	Optimal	OG	Domar	CPI	$\frac{\mathcal{U}^{\text{OG}} - \mathcal{U}^{\text{Domar}}}{\mathcal{U}^{\text{Optimal}} - \mathcal{U}^{\text{Domar}}}$
Mexico					
Total	-0.131	-0.133	-0.136	-0.368	57.2%
Output volatility	0.000	0.000	0.000	-0.029	
Luxemburg					
Total	-4.727	-4.744	-5.244	-6.144	96.7%
Output volatility	-0.003	0.000	-0.063	-0.206	

Note: simulate $P^*_{IM,iF}$ using the covariance matrix of it from WIOD

Outperforming Condition

- A policy is **outperformed** by the OG policy contingent on state ξ if

$$(\mathcal{V}\widehat{\xi})^\top \mathcal{L}\mathcal{B} \cdot \widehat{C}^{gap}(\xi) > 0.$$

Recall $U^{gap}(\xi) \propto -\frac{1}{2}\widehat{C}^{gap}(\xi)^2 - \frac{1}{2}\mathcal{B}^\top \mathcal{L}\mathcal{B} \cdot \widehat{C}^{gap}(\xi)^2 - (\mathcal{V}\widehat{\xi})^\top \mathcal{L}\mathcal{B} \cdot \widehat{C}^{gap}(\xi) - \frac{1}{2}(\mathcal{V}\widehat{\xi})^\top \mathcal{L}(\mathcal{V}\widehat{\xi}) + o(|\xi|^2)$

- This condition **holds quantitatively** when
  - OG weight $\propto$ sectoral sales to GDP ratio, or
  - OG weight $\propto$ sectoral consumption to GDP ratio

- We have checked that $(\mathcal{V}\widehat{\xi})^\top \mathcal{L}\mathcal{B}$ is usually negative under positive values of $\widehat{\xi}$, under which $\widehat{C}^{gap}(\xi) < 0 \rightarrow$ too much economic contraction.

Conclusion

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References

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