Rationally Inattentive Monetary Policy

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Motivation

- Lessons for optimal monetary policy are usually derived given complete information
- In reality, policy is set with limited information
  "Uncertainty about the current state of the economy is a chronic problem for policymakers" -Bernanke
- Due to limited information, policy will deviate from the full information benchmark
  - *How can the policy maker minimize the impact of their mistakes?*
  - *What should they focus their limited attention on?*
  - *What are the ramifications for macroeconomic dynamics?*

Contributions

- We study optimal monetary policy with rational inattention in an otherwise textbook New Keynesian model driven by demand and supply shocks
- The policy maker solves a Ramsey problem subject to a rational inattention constraint
- We study how this constraint affects the solution analytically and quantitatively

Analytical Results

- Demonstrate how the policy maker's information choices shape their expectations and the dynamics of the macroeconomy
- Rational inattention attenuates the policy maker's expectation formation process $\implies$ Monetary policy is less responsive to exogenous shocks
- Rational inattention "noises up" the policy maker's expectation formation process $\implies$ Monetary policy is subject to endogenous shocks
- Output responds relatively more to demand shocks and less to supply shocks vs. the efficient benchmark

Quantitative Results

- How does improved information processing by policy makers affect the macroeconomy?
- Outcomes converge towards the efficient benchmark
- Macro volatility and the co-movement between output and inflation all decline, consistent with empirical trends
- Optimal for policy makers to focus their attention on demand shocks
    - Intuition: persistent supply shocks have only a small effect on efficient interest rates

Literature

- Monetary policy with exogenous information
  Aoki (2003), Boehm and House (2019)
- Monetary policy when the private sector has limited information
  Paciello and Wiederholt (2014), Angeletos and La'O (2020)
- Robust monetary policy with uncertainty about private sector beliefs
  Woodford (2010), Adam and Woodford (2012)
- Flattening of the empirical Phillips curve
  McLeay and Tenreyro (2020)

Outline

- Environment
- Analytical Results
- Quantitative Results

Setting and Aggregate Shocks

- Economy is a textbook log-linear New Keynesian model
- Hatted variables denote log deviations from the deterministic steady state
- The economy is driven by two exogenous stochastic processes that drive the household discount rate $\hat{\rho}_t$ and total factor productivity (TFP) $\hat{a}_t$

$$\hat{\rho}_t = \delta_\rho \hat{\rho}_{t-1} + \sigma_\rho e_{\rho,t},$$
$$\hat{a}_t = \delta_a \hat{a}_{t-1} + \sigma_a e_{a,t},$$

  where $\delta_\rho, \delta_a \in [0, 1)$, $e_{\rho,t} \sim N(0, 1)$, and $e_{a,t} \sim N(0, 1)$
- We interpret and refer to these as demand and supply shocks

Flexible Price Benchmark

- Suppose that the economy is subject to demand shocks $\hat{\rho}_t$ and supply shocks $\hat{a}_t$
- When prices are flexible and monetary policy is neutral, outcomes are Pareto efficient and are described by starred variables for output and the real interest rate that satisfy:

$$\hat{y}_t^* = \frac{1+\varphi}{1/\gamma+\varphi}\hat{a}_t$$

$$r_t^* = \rho + \hat{\rho}_t - \frac{1+\varphi}{1/\gamma+\varphi}(1-\delta_a)\hat{a}_t$$

where $\gamma > 0$ is the elasticity of intertemporal substitution and $1/\varphi$ is the Frisch labor elasticity

Equilibrium Dynamics w/ Sticky Prices

- We analyze outcomes under sticky prices in terms of their deviations from the efficient benchmark (output gap $\tilde{y}_t = \hat{y}_t - \hat{y}_t^*$)
- Outcomes are described by the Euler equation and the New Keynesian Phillips curve:

$$\mathbb{E}_t \tilde{y}_{t+1} - \tilde{y}_t = \gamma \left(\iota_t - \mathbb{E}_t \pi_{t+1} - r_t^* \right)$$
$$\pi_t = \varphi_y \tilde{y}_t + \frac{1}{1+\rho} \mathbb{E}_t \pi_{t+1}.$$

- Optimal monetary policy with full-information:

$$\iota_t = r_t^* \implies \tilde{y}_t = \pi_t = 0, \quad \hat{y}_t = \hat{y}_t^*$$

Information Frictions

- We use Shannon mutual information to quantify how much information the policy maker processes about demand and supply shocks, and then uses to implement policy
- Define the average per-period mutual information between two stochastic processes: $\mathcal{I}(\{X\};\{Y\}) = \lim_{T\to\infty} \frac{1}{T} I(\mathbf{X};\mathbf{Y})$
- Information constraint:

$$\mathcal{I}\left(\{\hat{\rho}_t, \hat{a}_t\}; \{\mathbb{E}_{M,t}\left[\hat{\rho}_t\right], \mathbb{E}_{M,t}\left[\hat{a}_t\right]\}\right) \leq \kappa_M$$

- Assuming independent learning and independent shocks:

$$\underbrace{\mathcal{I}\left(\{\hat{\rho}_t\}; \{\mathbb{E}_{M,t}\left[\hat{\rho}_t\right]\}\right)}_{=\kappa_\rho} + \underbrace{\mathcal{I}\left(\{\hat{a}_t\}; \{\mathbb{E}_{M,t}\left[\hat{a}_t\right]\}\right)}_{=\kappa_a} \leq \kappa_M$$

- Finite $\kappa_M \implies$ policy maker cannot eliminate all uncertainty about r_t^*

Optimal Policy Problem

The optimal policy problem can be broken into two subproblems:

- First, in period $t = -1$ the policy maker chooses their information structure:
    - How much attention to allocate to supply vs. demand shocks?
    - This division characterizes how the expectations, $\mathbb{E}_M$, will be formed before any information is received
- Second, in each period $t \geq 0$, the policy maker chooses ι_t given their information set
- Let me begin by discussing the second subproblem

Ramsey Problem (Second Subproblem)

- To determine the optimal choice of ι_t the policy maker solves

$$\min_{\iota_t} \frac{1}{2}\mathbb{E}_{M,t}\left[\tilde{y}_t^2 + \frac{\xi}{1/\gamma + \varphi}\pi_t^2\right]$$

subject to

$$\pi_t = \varphi_y \tilde{y}_t + \frac{1}{1+\rho}\mathbb{E}_t \pi_{t+1}$$

$$\mathbb{E}_t \tilde{y}_{t+1} - \tilde{y}_t = \gamma\left(\iota_t - \mathbb{E}_t \pi_{t+1} - r_t^*\right)$$

- The optimal discretionary monetary policy satisfies $\iota_t = \mathbb{E}_{M,t}\left[r_t^*\right]$, so:

$$\iota_t = \rho + \mathbb{E}_{M,t}\left[\hat{\rho}_t\right] - \frac{1+\varphi}{1+\gamma\varphi}\mathbb{E}_{M,t}\left[\hat{a}_t\right].$$

- Optimal monetary policy is the subjective expectation of the optimal policy under complete information

Information Structure Choice (First Subproblem)

- Recall the information constraint:

$$\underbrace{\mathcal{I}\left(\{\hat{\rho}_t\};\{\mathbb{E}_{M,t}\left[\hat{\rho}_t\right]\}\right)}_{=\kappa_\rho}+\underbrace{\mathcal{I}\left(\{\hat{a}_t\};\{\mathbb{E}_{M,t}\left[\hat{a}_t\right]\}\right)}_{=\kappa_a}\leq\kappa_M$$

- To determine their information allocation, the policy maker minimizes the discounted expected welfare loss (conditional on the optimal policy)

$$\min_{\kappa_\rho,\kappa_a}\frac{1}{2}\mathbb{E}_{M,-1}\left[\sum_{t=0}^{\infty}\beta^t\left(\tilde{y}_t^2+\frac{\xi}{1/\gamma+\varphi}\pi_t^2\right)\right]$$

subject to

$$\kappa_\rho+\kappa_a\leq\kappa_M$$

Analytical Results

- Assume shocks are i.i.d. over time ($\delta_\rho = \delta_a = 0$)
- How does the policy maker form their expectations?
- Derive properties of $E_{M,t}$ in terms of the information capacity allocated to demand and supply shocks
    - κ_ρ and κ_a where $\kappa_\rho + \kappa_a = \kappa_M$

Policy Maker Expectations

- Policy maker's expectations of supply and demand shocks:

$$E_{M,t}\hat{a}_t = (1 - 1/2^{2\kappa_a})\hat{a}_t + (\sqrt{2^{2\kappa_a} - 1}/2^{2\kappa_a})\sigma_a v_t$$
$$E_{M,t}\hat{\rho}_t = (1 - 1/2^{2\kappa_\rho})\hat{\rho}_t + (\sqrt{2^{2\kappa_\rho} - 1}/2^{2\kappa_\rho})\sigma_\rho u_t$$

where $v, u \sim N(0, 1)$

- Limited information ($\kappa_a < \infty$) $\Rightarrow$ policy maker attenuates their expectation towards their prior, $\hat{a}_t = 0$
- Processing some information ($\kappa_a > 0$) $\Rightarrow$ expectation formation is subject to noise
- Similar intuition for $E_{M,t}\hat{\rho}_t$

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Optimal Path for Nominal Rates

- Now we can write the optimal path of nominal (equal to real) rates as:

$$\iota_t = \rho + (1 - 1/2^{2\kappa_\rho})\hat{\rho}_t + (\sqrt{2^{2\kappa_\rho} - 1}/2^{2\kappa_\rho})\sigma_\rho u_t$$
$$- \tfrac{1+\varphi}{1+\gamma\varphi}((1 - 1/2^{2\kappa_a})\hat{a}_t + (\sqrt{2^{2\kappa_a} - 1}/2^{2\kappa_a})\sigma_a v_t)$$

- Muted response to to exogenous demand and supply shocks (relative to the efficient benchmark where $\iota_t^* = \rho + \hat{\rho}_t - \frac{1+\varphi}{1/\gamma+\varphi}(1 - \delta_a)\hat{a}_t$)
- Endogenous and stochastic shocks to optimal monetary policy that a policy maker with full information could avoid
- Informational trade-off: monetary policy responds more strongly and more precisely to the shock that the policy maker pays more attention

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Output Dynamics

- Combining the nominal rate, Euler equation and New Keynesian Phillips curve, we can solve for output:

$$\hat{y}_t = \gamma(\hat{\rho}_t/2^{2\kappa_\rho} - (\sqrt{2^{2\kappa_\rho} - 1}/2^{2\kappa_\rho})\sigma_\rho u_t)$$
$$+ \frac{1+\varphi}{1/\gamma+\varphi}((1 - 1/2^{2\kappa_a})\hat{a}_t + (\sqrt{2^{2\kappa_a} - 1}/2^{2\kappa_a})\sigma_a v_t)$$

- Compare to efficient output process: $\hat{y}_t^* = \frac{1+\varphi}{1/\gamma+\varphi}\hat{a}_t$
- Output responds less to supply shocks
    - Muted real rate response $\Rightarrow$ less intertemporal substitution
- Output responds more to demand shocks
    - Larger gap between real rate and discount rate $\Rightarrow$ more intertemporal substitution
- Output has endogenous fluctuations driven by noisy expectations

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Inflation Dynamics

- Substituting the dynamics for output into the New Keynesian Phillips curve:

$$
\begin{aligned}
\pi_t = {} & \varphi_y \gamma(\hat{\rho}_t / 2^{2\kappa_\rho} - (\sqrt{2^{2\kappa_\rho} - 1}/2^{2\kappa_\rho})\sigma_\rho u_t) \\
& + \varphi_y \tfrac{1+\varphi}{1/\gamma+\varphi}(-\hat{a}_t / 2^{2\kappa_a} + (\sqrt{2^{2\kappa_a} - 1}/2^{2\kappa_a})\sigma_a v_t)
\end{aligned}
$$

- Inflation responds to demand and supply shocks, in sharp contrast with its stability under the full information policy
- Inflation responds positively to demand shocks, but negatively to supply shocks
- The inflation response to each shock depends on the information allocation
    - More response to the shock that the policy maker devotes less attention

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& + \varphi_y \tfrac{1+\varphi}{1/\gamma + \varphi} (-\hat{a}_t / 2^{2\kappa_a} + (\sqrt{2^{2\kappa_a} - 1} / 2^{2\kappa_a}) \sigma_a v_t)
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Information Allocation (IID Assumption)

- Having characterized the optimal monetary policy and equilibrium dynamics, we can solve for the optimal information allocation (the first subproblem)
- The policy maker minimizes ex-ante utility loss, subject to their information constraint:

$$\min_{\kappa_\rho, \kappa_a} \frac{1}{2} \left(\frac{\sigma_\rho^2}{2^{2\kappa_\rho}} + \left(\frac{1+\varphi}{1+\gamma\varphi} \right)^2 \frac{\sigma_a^2}{2^{2\kappa_a}} \right)$$

subject to:

$$\kappa_\rho + \kappa_a \leq \kappa_M$$

Information Allocation (IID Assumption)

- Solution:

$$\kappa_a = \begin{cases} 0 & \text{if} \quad \log_2\left(\frac{1+\varphi}{1+\gamma\varphi}\sigma_a/\sigma_\rho\right) \leq -\kappa_M, \\ \frac{1}{2}\kappa_M + \frac{1}{2}\log_2\left(\frac{1+\varphi}{1+\gamma\varphi}\sigma_a/\sigma_\rho\right) & \text{if} \quad \log_2\left(\frac{1+\varphi}{1+\gamma\varphi}\sigma_a/\sigma_\rho\right) \in (-\kappa_M, \kappa_M), \\ \kappa_M & \text{if} \quad \log_2\left(\frac{1+\varphi}{1+\gamma\varphi}\sigma_a/\sigma_\rho\right) \geq \kappa_M, \end{cases}$$

  and $\kappa_\rho = \kappa_M - \kappa_a$

- The policy maker chooses their information allocation based on the welfare gains from reducing demand shock variance vs. supply shock variance
- κ_a is increasing in the relative gain from reducing the welfare impact of supply shocks

Quantitative Exercise

- Relax i.i.d. shocks assumption and solve model numerically
  - Set parameters governing preferences and technology consistent with literature
  - Calibrate parameters governing the exogenous shock processes and the information processing capacity
- Consider a range of values for κ_M and ask how an increase in κ_M affects macro dynamics?
- Should the policy maker pay more attention to demand or supply shocks?

Calibration

We calibrate the parameters governing the exogenous shock processes and the information processing capacity to target 5 summary statistics from our sample:

Parameter	Value	Target	Data	Model
δ_a	0.951	$AC(\hat{y})$	0.871	0.812
σ_a	0.005	$SD(\hat{y})$	0.015	0.018
δ_ρ	0.644	$AC(\pi)$	0.336	0.364
σ_ρ	0.006	$SD(\pi)$	0.015	0.011
κ_M^*	0.844	$Cov(\hat{y},\pi)/V(\hat{y})$	0.233	0.228

Optimal to Focus on Demand Shocks

Optimal information allocation, expressed as percentages of κ_M ($\kappa_M^* = 0.84$)

κ_M	0.57	0.62	0.68	0.73	0.79	0.84	0.9	0.95	1.01	1.07	1.12
κ_a	55	51	48	45	43	41	39	38	36	35	34
κ_ρ	45	49	52	55	57	59	61	62	64	65	66

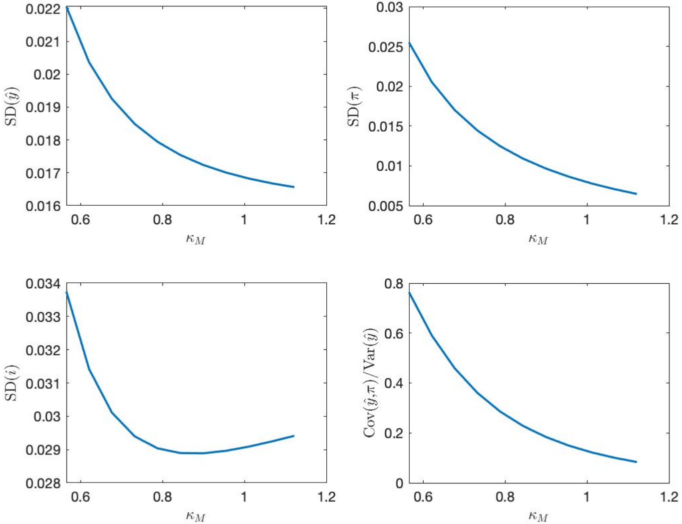
Two effects:

- Supply shocks are more persistent in our calibration, so their variance is also larger $\implies$ policy maker should pay relatively more attention to supply shocks
- Persistent supply shocks have a weak effect on the efficient real rate ($r_t^* = \rho + \hat{\rho}_t - \frac{1+\varphi}{1/\gamma+\varphi}(1-\delta_a)\hat{a}_t$) $\implies$ policy maker should pay relatively less attention to supply shocks

text analysis

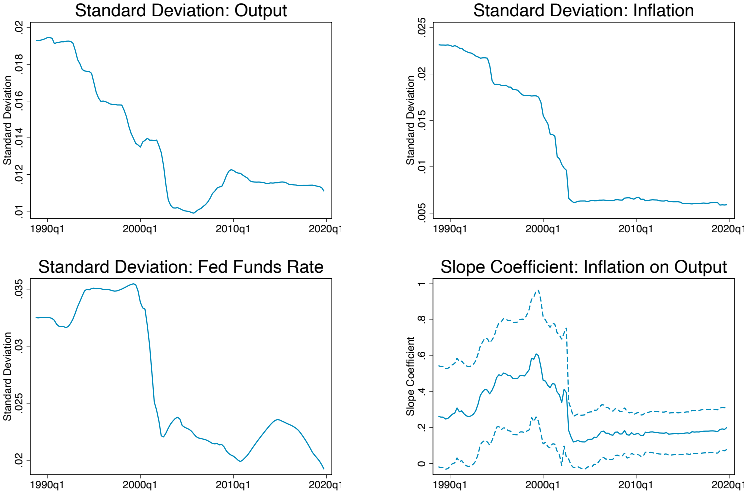
Macro Volatility Declines in κ_M

As κ_M increases, outcomes approach their efficient counterparts



Empirical Decline in Macro Volatility and Phillips Curve

Consistent with an increase in processing capacity, there has been a decline in macroeconomic volatility and the correlation between inflation and real activity



Extensions

- Linear marginal information cost
  - Results are robust and can be mapped from one approach to the other
- Random walk supply shocks
  - Assuming $\delta_a = 1$, r_t^* does not depend on supply shocks at all and the policy maker pays attention only to demand shocks
- Mark up shocks
  - The policy maker still chooses an optimal information allocation to try and get as close to the efficient allocation as possible - key takeaways remain the same
- Alternative information cost
  - Results robust to using the neighborhood-based information cost function proposed by Hébert and Woodford (2020)

Conclusion

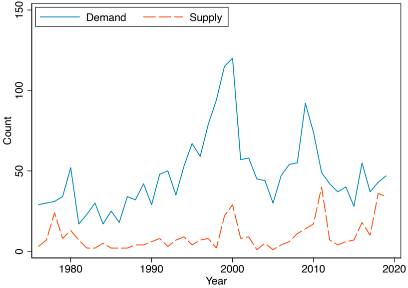
- We solve the rationally inattentive optimal monetary policy problem in a New Keynesian model
- Policy responds less to exogenous shocks, but is endogenously noisy
- Typically, policy makers should focus on understanding demand factors
- Improvements in information processing are consistent with the decline in macro volatility and the disappearing co-movement between output and inflation in the data

FOMC Minutes: Text Analysis

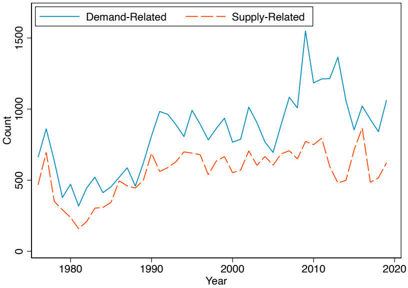
- Compile the text of the FOMC Minutes from 1976
- Remove 179 stop words such as ‘and’, ‘the’, and ‘we’
- Create a list of the 1,000 most commonly used words and manually classify each word as being demand- or supply-related or neither
    - Example demand-related words: consumer, spending, sentiment
    - Example supply-related words: energy, industrial, shipments
- Given the subjective nature of this allocation, we include analyses not only on the identified demand-related and supply-related words, but also on the use of the exact words ‘demand’ and ‘supply’

FOMC Minutes: Demand and Supply Counts

‘Demand and demand-related words are consistently used more than ‘supply’ and supply-related words. Consistent with our calibration where 59% of processing capacity is allocated to demand and 41% to supply factors



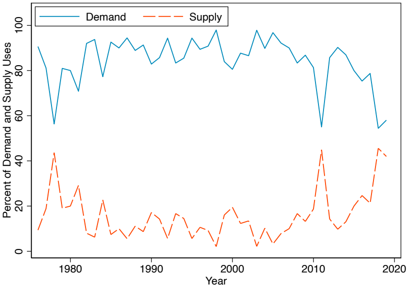
(a) ‘Demand’ or ‘Supply’ Word Count



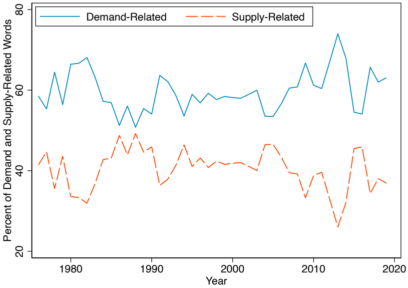
(b) Demand- or Supply-Related Word Count

FOMC Minutes: Demand and Supply Percents

We find demand-related terminology has modestly increased relative to supply-related terminology over time - consistent with a small increase in information processing capacity



(a) 'Demand' or 'Supply', % of 'Demand' & 'Supply'



(b) Demand or Supply-Related Words, % of Demand & Supply-Related

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