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Monetary Policy in a Volatile World: ToTEM Simulations

Edward Booth
Economic and Financial Research Department
Bank of Canada
EBooth@bank-banque-canada.ca

Edouard Djeutem
International Economic Analysis Department
Bank of Canada
ETsagueDjeutem@bank-banque-canada.ca

Oleksiy Kryvtsov
Economic and Financial Research Department
Bank of Canada
okryvtsov@bank-banque-canada.ca

Fanny McKellips
Canadian Economic Analysis Department
Bank of Canada
FMcKellips@bank-banque-canada.ca

Yang Zhang
Canadian Economic Analysis Department
Bank of Canada
yangzhang@bank-banque-canada.ca

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Abstract

Relative to the pre-pandemic period, supply shocks in the Bank of Canada's Terms-of-Trade Economic Model (ToTEM) have been moderately larger since 2022, and markedly larger if 2020–21 pandemic is included. ToTEM simulations show that moderately larger supply shocks increase inflation volatility without materially worsening the medium-term inflation outlook or significantly increasing recession risks. When supply shocks are especially large, however, episodes of core inflation outside of the 1–3% control range become both more frequent and more persistent, and recession risks rise sharply. In these environments, monetary policy faces more challenging trade-offs as stabilizing inflation increasingly entails costs to real activity, and even more aggressive policy rules cannot replicate inflation outcomes in more stable periods. Amplification of inflationary risks—due to de-anchoring inflation expectations or high costs pass-through—worsen these trade-offs and reduce the scope to look through inflationary shocks. When such amplification is present, a much tighter policy response than the one embedded in the historical rule is warranted to manage more frequent high-inflation states and ensure price stability.

Introduction

In this note, we summarize the results of simulations using the medium-scale policy model, ToTEM III' (March 2025).[1] The goal is to illustrate how the trade-offs facing the central bank change in the environment with larger and more persistent supply shocks.

The analysis consists of four parts. First, we compare the outcomes between the *Normal* and *Shock-Prone* versions of the model corresponding to different supply-side volatility, under the historical policy rule. Second, we vary the parameters of the interest-rate policy rule and map out inflation-output outcome frontiers. Third, we simulate different versions of the model with *Shock-Prone* volatility to assess the shifts of inflation-output frontiers. Fourth, we assess which deviations of policy from the historical policy rule deliver better inflation-output outcomes.

Normal, moderate and large Shock-Prone versions

Simulations are based on the variance-covariance matrix Ω of i.i.d. innovations for the exogenous shock processes obtained from ToTEM's estimation. Out of 55 total shocks in ToTEM, we focus on 36 shocks, 12 of which are classified as demand shocks and 22 are supply shocks.[2] We consider 3 alternative versions of the model featuring varying prevalence of supply shocks. We refer to the first version of the model as "*Normal*", Ω is informed by ToTEM shocks for the inflation targeting pre-covid period 1995Q1–2019Q4. In an alternative version of the model "*Shock-Prone (Moderate)*", we replace the variances of innovations of all supply shocks with those corresponding to post-covid period 2022Q1–2025Q2. This period includes the post-covid inflation surge and the 2025 tariff war, and it exemplifies the type of environment in which larger supply disturbances may challenge monetary policy going forward. Lastly, in the third version of the model we label as "*Shock-Prone (Large)*", we restrict the sample period to 2020Q1–2025Q2, i.e., including the first two years of the pandemic to help proxy an environment where larger and more frequent supply shocks are present.[3] In all simulations, parameters governing the persistence of shocks are held constant.

Differentiating two Shock-Prone versions is helpful for demonstrating implications between economic landscapes with moderately larger and significantly larger supply

[1] ToTEM III technical report is provided in Corrigan et al. (2021). Simulation is based on an updated version of ToTEM estimated with data extending to 2025.

[2] A simple definition is used, where a demand shock is generally defined as a shock that moves output and inflation in the same direction, while a supply shock is defined as one that moves them in opposite directions.

[3] The models used in our simulation are linear, e.g., it does not include an effective lower bound (ELB) constraint on the policy interest rate). Therefore, all outcomes for inflation and output are symmetric around steady state. We will focus on inflationary outcomes.

shocks. The average standard deviation of the supply shocks in the *Shock-Prone (Moderate)* version is 1.4 times the standard deviation of those in the *Normal* baseline, and it is 2.2 times in the *Shock-Prone (Large)* version. This implies, assuming a normal distribution of shocks, that a shock that happens 5% of time in *Normal* baseline (i.e., its size is at least two standard deviations in absolute magnitude), will occur around 8% of time in *the Shock-Prone (Moderate)* version, and 18% of time in *Shock-Prone (Large)* version.

Given the variances, the model is simulated 5000 times. Each simulation draws a sequence of shocks for 101 quarters. The model predicts the evolution of outcomes (for inflation, output gap, policy rate, etc.) starting from the steady state.

We focus on reporting two key statistics from our simulation—related to inflation and the change in output. In particular, we ask how often year-over-year inflation (headline or core) reaches 3% and, for each time it hits 3%, how long it stays above 3%.[4] Combined, the likelihood and duration of inflation above 3% give the frequency of observing a quarter with inflation above 3%. The second set of statistics focuses on recession events, defined as at least two consecutive quarters of negative output growth. We ask how often the economy enters a recession and how long a recession lasts. Combining the number and duration of a recession gives the frequency of quarters with the economy in a recession.

Table 1 compares these statistics for the three versions. In *Shock-Prone (Moderate)* simulations, both inflation and output volatility increase. Probability of core inflation crossing over 3% in a given quarter more then triples relative to *Normal* simulations, from 1.1% to 3.7%. However, the duration of the episodes with core inflation above 3% is almost the same as in *Normal* baseline, at 3.5 quarters. Probability of starting a recession increases only slightly from 5.6% to 6.4%. Hence, moderately larger supply shocks increase inflation volatility without significantly worsening medium-term inflation outlook while keeping recessionary risks about the same.

Table 1. Key statistics for *Normal* and *Shock-Prone* versions

	Recession			Core inflation, YoY %			CPI inflation, YoY %		
	Start	Dur	Freq	Hit 3%	Dur	Freq	Hit 3%	Dur	Freq
Data (1995Q1-2019Q4)	2.0	2.5	5.0	1.0	1.0	1.0	16.0	1.4	22.0
Model simulations									
Normal	5.6	2.5	13.9	1.1	3.4	3.8	6.2	3.4	21.0
Shock-Prone Moderate (2022Q1-2025Q2)	6.4	2.5	16.2	3.7	3.5	13.0	6.3	3.7	23.4
Shock-Prone Large (2020Q1-2025Q2)	8.2	2.6	21.2	3.7	5.5	20.4	5.8	4.7	27.3

Notes: Columns are "Start" – frequency of observing a start of a recession (%), "Dur" – duration of a recession or inflation above 3% (in quarters), "Freq" – frequency of observing a recessionary

[4] The empirical counterpart of core inflation in the model is the equal weighted average of CPI core median and CPI core trim, see https://www.bankofcanada.ca/rates/indicators/key-variables/key-inflation-indicators-and-the-target-range/. In the model, CPI inflation is the sum of core inflation, the change in log real price of domestically distributed commodity good and consumption tax.

quarter or inflation above 3% (in %). *Normal* baseline simulations assume shock variances from ToTEM shocks for 1995Q1–2019Q4 sample. *Shock-Prone (Moderate)* version simulations assume shock variances from ToTEM supply shocks for 2022Q1–2025Q2 sample; and *Shock-Prone (Large)* version is based on 2020Q1–2025Q2 sample.

In *Shock-Prone (Large)* case, the duration of above-3% core inflation increases from 3.5 quarters to 5.5 quarters and the frequency of hitting a recession increases from 6.4% to 8.2%. Hence, the key difference between two Shock-Prone cases is that when supply shocks are moderate, the economy hits 3% more frequently but does not stay above 3% longer than in normal times, and the recession risks increase only slightly. In contrast, when supply shocks are significantly larger, both the frequency and *persistence* of above 3% inflation episodes increase, and recession risks also increase significantly.

The differences for CPI inflation are not as striking as for the core inflation: the frequency of quarters with above 3% CPI inflation goes up from 21.6% to 23.4% and to 27.3% in the two *Shock-Prone* versions. This is because most of the deviations of CPI inflation above 3% are transient in the data: CPI inflation hits the upper bound 6.2% of time in normal times versus only 1.1% of time for core CPI inflation. Since short-term volatility in CPI inflation could potentially mask the dramatic increase in volatility of the core inflation, measurement of persistent inflationary pressures is more important in the environment with larger supply shocks.

Inflation-output trade-offs

To illustrate the challenges for inflation stabilization in a shock-prone environment, we conduct stochastic simulations for each version across the spectrum of policy rules with varying degree of aggressiveness in response to inflation fluctuations. The historical policy rule is

$$R_t = \Theta_R R_{t-1} + (1-\Theta_R)\overline{R_t} + (1-\Theta_R)\Theta_\pi \left(\frac{1}{H}\sum_{k=1}^{H} \mathrm{E}_t \pi_{t+k} - \overline{\pi_t}\right) + (1-\Theta_R)\Theta_y \widetilde{Y_t} \ , \qquad (1)$$

where R_t denotes the policy rate, Θ_R is the smoothing coefficient, $\overline{R_t}$ represents the short-term neutral nominal rate, π_t is core inflation, $\overline{\pi_t}$ is the inflation target, and $\widetilde{Y_t}$ is the output gap. Coefficients Θ_π and Θ_y control the sensitivity of the policy rate to deviations of core inflation from the target and to output gap, respectively, and H is the policy horizon.

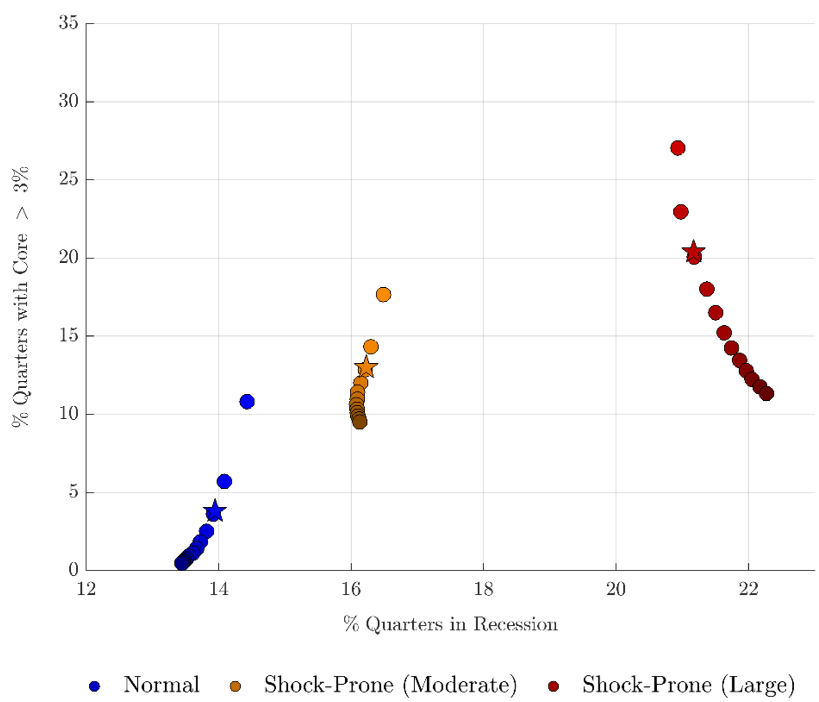
In the historical policy rule (1), $\Theta_\pi = 4.65$.[5] We repeat simulations for *Normal* and *Shock-Prone* versions while varying this sensitivity from low ($\Theta_\pi = 1.5$) to high ($\Theta_\pi = 20$). These variations can be interpreted as the changes in the degree of inflation control desired by an inflation-targeting central bank, keeping its preference for output gap stabilization,

[5] The other coefficient values are $H = 4$, $\Theta_R = 0.85$, $\Theta_y = 0.4$.

interest-rate smoothing and policy horizon unchanged. **Chart 1** shows the sets of inflation and output outcomes as monetary policy becomes increasingly aggressive in controlling inflation.

In the *Normal* baseline, where demand shocks are relatively more prevalent than supply shocks, increasingly aggressive monetary policy stabilizes both inflation and output fluctuations, leading to lower incidence of both above-3% inflation and a recession. This result reflects a well-known "divine coincidence" feature of monetary policy in models with mostly demand-side disturbances.[6] Given the mix of demand and supply shocks in the *Normal* baseline, the size of supply shocks is not large enough relative to the size of demand shocks, implying that a more aggressive policy rule delivers *on average* both inflation and output stabilization. So even when monetary policy cannot respond differently to demand and supply shocks, desirable inflation outcomes usually mean desirable output outcomes at the same time, as long as supply shocks are relatively small.

Chart 1. Inflation and output outcomes in model simulations



<u>Notes:</u> Each dot corresponds to average % of quarters with core inflation above 3% (y-axis) and average % of quarters in a recession across 5000 simulations (x-axis) in *Normal* baseline (blue), *Moderate Shock-prone* version (orange) and *Shock-prone* version (red). For each version we repeat

[6] When there are no supply (cost-push) shocks, the only force moving inflation is demand-driven movements in the output gap, which monetary policy can offset by raising or lowering the interest rate to steer aggregate demand. As a result, an inflation-stabilizing interest-rate policy also pins down the output gap at (or near) zero—hence the "divine coincidence."

simulations varying policy rule inflation coefficient from low $\Theta_{\pi} = 1.5$ to high $\Theta_{\pi} = 20$ (darker dots correspond to higher values). Star denotes the outcomes under historical rule $\Theta_{\pi} = 4.65$.

When supply shocks become relatively more important in *Shock-Prone (Moderate)* and *Shock-Prone (Large)* simulations, the inflation-output frontier shifts out and pivots counter-clockwise, implying a trade-off between stabilizing these two objectives. In *Shock-Prone (Moderate)* case where supply shock is more prevalent than in *Normal* baseline, a more aggressive inflation-targeting monetary policy stabilizes inflation but no longer significantly improves the odds of a recession, since the frequency of observing both elevated inflation and excess supply is higher. When supply shocks are even larger, in *Shock-Prone (Large)* version, an aggressive inflation-targeting monetary policy reduces the probability of high inflation, but at the expense of *increasing* the frequency of recessionary quarters. Hence, when supply shocks are large enough in our simulations, stabilizing inflation is achieved at a cost of *de-stabilizing* output.[7]

There are two implications of relatively larger supply shocks for monetary policy implemented via policy rule (1).

There is a limit to how much inflation control can be achieved. Even a very aggressive monetary policy stance falls short of bringing inflation within the 1–3% range at levels seen in *Normal* simulations. In the *Normal* baseline, sufficiently aggressive interest rate policy can reduce probability of inflation going outside the 1–3% range practically to zero (0.5% of quarters). In contrast, in both *Shock-Prone* cases, even the most aggressive policy rule allows inflation outside the band 9.5% (11.3%) of time for moderate (large) supply shocks. This is because unlike for demand shocks, monetary policy cannot "turn off" inflation by adjusting the interest rate and closing the output gap at the same time. When supply shocks are present, reducing inflation volatility can only come at a cost of increasing output volatility. This trade-off becomes increasingly difficult when the Phillips curve is flatter, and when monetary policy cannot respond to inflation fluctuations quickly (e.g., due to a monetary policy lag, interest rates smoothing, incomplete or imperfect information about inflation surprises).

Only substantially large supply shocks represent a challenge for stabilizing inflation. Even when supply-side shocks are moderately more volatile relative to normal times—e.g., when their standard deviation is 1.4 times higher in the *Shock-Prone (Moderate)* version—a more aggressive inflation targeting rule can stabilize inflation without deterioration in output volatility. In this sense, monetary policy has "more space" for stabilizing inflation so long as the supply shock size is moderate. This policy space

[7] Not all supply shocks in the model imply that after an adverse shock output gap will be negative. A well-known example is an adverse aggregate total factor productivity (TFP) shock.

shrinks as supply-side shocks become much larger. In the *Shock-Prone (Large)* version—when standard deviation of supply-side shocks is 2.2 times higher than in normal times and the risks of inflation above 3% are elevated—stabilizing inflation would require much larger output costs. In the rest of the note, we will focus on the results based on the *Shock-Prone (Large)* case and illustrate how this trade-off changes under alternative model assumptions.

Together, these results also offer several takeaways for how monetary policy is implemented *in practice* in the environment with larger and more frequent supply shocks.

Central bank will face trade-offs more frequently. In the model, monetary policy does not distinguish between the sources of inflation and output fluctuations, it simply follows a policy rule (1). It is equivalent to assuming that the central bank sets interest rate without knowing whether a demand shock or a supply shock (or their combination) is driving inflation and output in real time. Although central banks do not have a crystal ball and do not know with certainty the nature of the underlying shocks, they often know enough, especially if the shocks are large.[8]

When the central bank can distinguish demand- and supply-driven inflation fluctuations, it can vary the degree of control accordingly. After a demand-driven inflationary shock, monetary policy can stabilize both inflation and output gap by tightening. After a small to moderate supply-driven inflationary shock, monetary policy can initially forgo tightening to minimize exacerbating output losses, as long as inflation is anticipated to self-correct when the shock dissipates. In a world with larger, more persistent and more frequent supply shocks, central banks will more frequently face a situation when they need to decide whether and how to look through supply shocks and adapt the policy response promptly to ensure price stability.

As **Chart 1** indicates, a larger magnitude of the supply shocks implies larger fluctuations in inflation and output gap. At the same time, **Table 1** shows that larger supply shocks also increase the duration of episodes with above-3% core inflation, i.e., it is more likely that a large enough shock can significantly increase the risk that inflation will stay about 3% over the medium term. Therefore, while recognizing a more challenging trade-off in the presence of larger supply shocks, inflation-targeting central banks will less likely look through such shocks, and instead, will respond to limit medium-term inflation risk and ensure anchored inflation expectations.

Central banks need to improve supply-side intelligence. Distinguishing the source of the inflation deviations from the target in real time, therefore, becomes even more important in a shock-prone world. Central banks can achieve that with better supply-side

[8] Two recent examples are the 2025 tariff war (July 2025 MPR *Monetary Policy Report*) and the 2026 oil shock (April 2026 *Monetary Policy Report*).

analysis using better models and faster and more detailed data such as pricing data along the supply chain (e.g., PPI data), micro pricing data and information from survey and lab experiments on firms' pricing behavior

Alternative scenarios in a Large Shock-Prone world

A standalone supply-shock is unlikely to elicit a policy response unless it is large enough to prevent inflation from correcting over the medium term. On the other hand, supply shocks may have larger effects on inflation if the economy is already strong, or they may trigger mechanisms that amplify inflation fluctuations and increase medium-term inflation risks (Briganti et al., 2025). We, therefore, consider how output losses and inflation stability in the *Shock-Prone (Large)* case change in simulations of alternative versions of the model in which these circumstances occur more frequently.

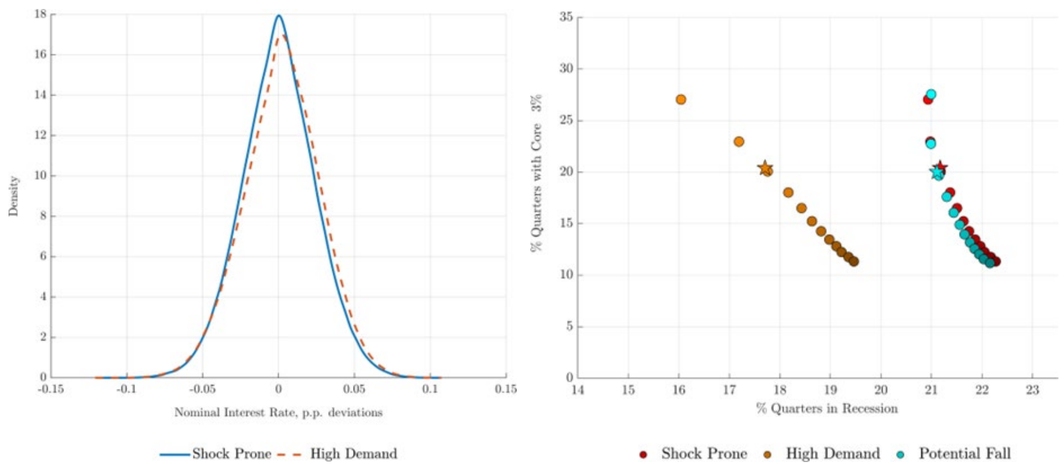
The economy is stronger at the time of the supply shock

If the inflationary cost-push shock occurs in an economy featuring stronger than average demand conditions, one would expect to see higher inflation, and higher interest rates. We refer to this as a "*High demand*" scenario. To illustrate the inflation-output trade-offs in this case, we re-compute inflation and output outcomes from the subset of simulated quarters in the *Shock-Prone (Large)* version discarding the quarters when core inflation was below 2% and final consumption was *below* steady state. The remaining subset of quarters therefore has a larger proportion of quarters with inflationary supply shocks and strong demand at the same.

When a cost-push shocks hits and the economy is in excess demand, the output gap often remains positive despite the adverse supply shock. In this case, the interest rule (1) implies that monetary policy will be on average more restrictive than in the baseline: **Chart 2a** shows that indeed the distribution of interest rates shifts to the right in *High Demand* scenario. Higher interest rates, in turn, stabilize inflation. Altogether, the inflation-output frontier shifts inward, as illustrated in **Chart 2b**. Hence, if the supply shock hits at the time when the economy is strong (e.g., the economy is in excess demand), there is less concern about the negative impact on the real economy, and monetary policy will usually respond more aggressively to reduce inflationary risks.

A similar result is obtained in a scenario when an adverse supply shock's total impact is divided between lowering potential output and lowering output level relative to potential output (i.e., excess supply). Indeed, supply disturbances like trade-fragmentation or adoption of AI may have a long-lasting effect on the economy's ability to produce, in addition to their business cycle effects. In an alternative scenario that captures this idea, we simulate a version of ToTEM where inflationary supply shocks also lower potential output.[9] In this scenario, the difference between output and its potential, i.e., output gap, is smaller and short-lived, weakening the disinflationary forces arising from excess supply. Under the policy rule (1), this implies a slightly tighter monetary policy stance and a more persistent inflation response, all else equal. Tighter policy stabilizes inflation, shifting the trade-off inward.

Chart 2. More room for policy stabilization with initial excess demand



a. Distributions of nominal interest rates **b. Trade-offs**

<u>Notes:</u> Each dot corresponds to average % of quarters with core inflation above 3% (y-axis) and average % of quarters in a recession across 5000 simulations. For the *High Demand* scenario, the inflation and output outcomes are calculated using the subset of quarters from the *Shock-prone (Large)* simulations, discarding the quarters when core inflation was below 2% and final consumption was below steady state. Star denotes the outcomes under historical rule $\Theta_\pi = 4.65$.

Mechanisms that amplify inflation risks

There also exist mechanisms that could amplify inflation risks from an adverse supply shock. Such mechanisms can be broadly classified in three groups: 1) the inflationary supply shock places the economy on a steep part of the Phillips curve,[10] 2) the pass-through of the cost-push shock to prices increases with inflation,[11] and 3) inflation

[9] For all simulations, we assume that potential output in all sectors (Core consumption good, Residential investment good, Business investment good, Government good, Non-commodities export good, Commodities) is influenced by output levels. This implies that any shock has both a cyclical and secular impact.

[10] In Benigno and Eggertsson (2025) a negative labor-supply–type disturbance raises labor market tightness, placing the economy in the steep part of the Phillips curve. In Harding, Lindé, Trabandt (2025), firms optimally raise prices disproportionately more to protect their markups after a cost-push shock than they would cut prices when costs fall.

[11] In Karadi et al. (2025), when inflation increases, firms reprice more frequently, making prices more flexible and steepening the Phillips curve endogenously. In Ghassibe and Nakov (2025) a cost-push shock triggers

expectations de-anchor from the target[12]. We, therefore, consider how output losses and inflation stability in the *Shock-Prone (Large)* case change in two alternative scenarios: "*Steep New Keynesian Phillips Curve (NKPC)"*—this scenario captures mechanisms in groups 1 and 2 above—and "*De-anchored*" scenario. **Chart 3** compares how inflation-output trade-offs in both alternative scenarios move relative to the *Shock-Prone (Large)* baseline.

"Steep NKPC" scenario. In the first scenario, the slope of final-good NKPC in ToTEM is higher by a factor 1.33.[13] Higher sensitivity of inflation to marginal costs increases deviations of inflation from the target. The resulting tighter policy response lowers some of that deviation by making the output gap more negative, thereby increasing the probability of a recession. As a result, the trade-off shifts out (green dots). Under historical rule, for example, probability of core inflation reaching above 3% increases from 20.4% to 23.1%., and probability of the economy being in a recession increases slightly from 21.2% to 21.3%.

"De-anchored" scenario. Even when the Phillips Curve remains as flat as in the *Shock-Prone (Large)* baseline, inflation fluctuations can be amplified when inflation expectations become de-anchored. In this scenario, there is a feedback from higher inflation to higher expected inflation which in turn feeds back into higher inflation. The impact from such feedback loop is stronger the larger the inflation responses. As a result, the trade-off between inflation and output gap losses pivots clockwise (magenta dots). Under historical rule, for example, probability of core inflation above 3% increases from 20.4% to 22.7%, and probability of being in a recession increases from 21.2% to 21.9%.

In the *Shock-Prone (Large)* baseline and both alternative scenarios, the inflation-output frontiers curves are convex, indicating that the sacrifice ratio—the output cost of bringing inflation down by and additional percentage point—are increasing as inflation becomes more stable. In standard linear New Keynesian models like ToTEM, aggressive policy stabilizes inflation and the output gap in response to demand shocks, but a trade-off remains under cost-push shocks, implying larger output losses to contain inflation

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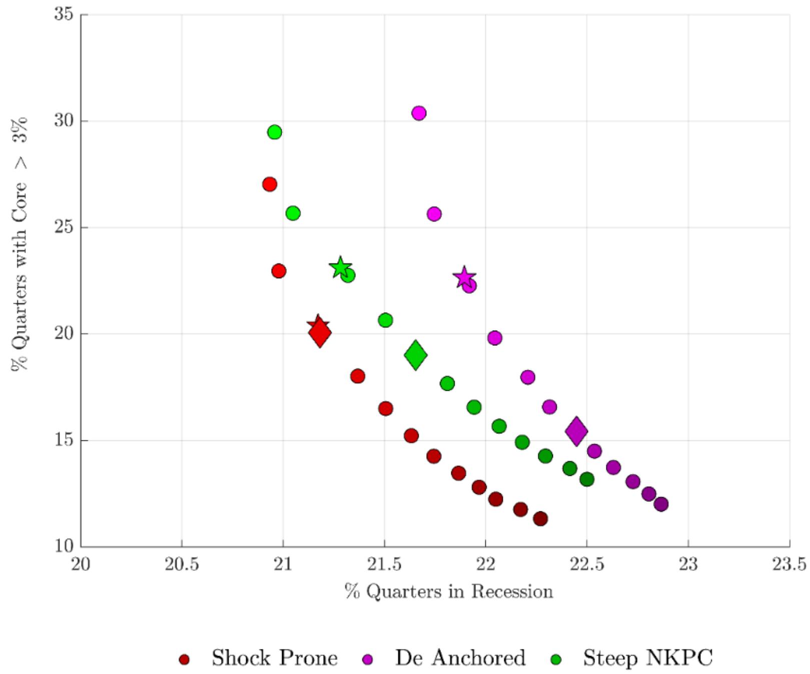
sequential price increases (*pricing cascades*) of firms along the input-output supply chain, generating nonlinear and persistent inflation far larger than the original shock.

[12] In Beaudry et al. (2023), when central banks initially "look through" temporary supply shocks, boundedly rational agents begin raising their inflation expectations, which then enter wage and price-setting and create a wage–price spiral. In Gust et al. (2025), firms and households rely on short planning horizons to form economic expectations. An adverse supply shock triggers a delayed but stronger surge in expected inflation, which then feeds back into pricing decisions and amplifies the inflation response to the shock.

[13] Internal staff's estimates using non-linear version of ToTEM (Lepetyuk, Maliar, Maliar 2020) suggest an increase in the slope of NKPC during 2020–2022 In this alternative scenario in ToTEM, we characterize a steeper NKPC through an increase in the slope of NKPC in final goods sector by a factor of 1.33. We calibrate such increase by reducing the share of the rule-of-thumb price setters in the final good sector to approximate the increased sensitivity of firms' output prices to input costs as discussed, for example, in the *Business Outlook Survey—Third Quarter of 2021*.

(Clarida, Galí, and Gertler 1999; Woodford 2003). This feature of standard New Keynesian models implies that it is more difficult for monetary policy to stabilize inflation near the target than away from the target, because in the vicinity of the target additional disinflation can come mainly through real slack, i.e., additional output gap.[14]

Chart 3. Steeper NKPC or de-anchored inflation expectations could worsen monetary policy trade-offs



Notes: Each dot corresponds to average % of quarters with core inflation above 3% (y-axis) and average % of quarters in a recession across 5000 simulations in *Shock-prone (Large)* baseline (brown) and two scenarios. For each baseline and scenario we repeat simulations varying policy rule inflation coefficient from low $\Theta_\pi = 1.5$ to high $\Theta_\pi = 20$ (darker dots correspond to higher values). Star denotes the outcomes under historical rule $\Theta_\pi = 4.65$. Diamond denotes the outcomes that minimize central bank's objective function (2).

Furthermore, in *De-anchored* scenario, the entire trade-off pivots clockwise relative to the baseline scenario. The pivot indicates that when inflation accelerates, the sacrifice ratio also decreases faster than in the baseline or in *Steep NKPC* scenario. This implies that a more forceful tightening of policy rates would be more effective and less costly in

[14] A higher sacrifice ratio at low and stable inflation can also arise in nonlinear NKPC models which imply that at low inflation the curve is flatter, so achieving a given change in inflation requires larger movements in real activity even in response to demand disturbances (Benigno and Eggertsson 2023; Blanco et al. 2025).

stabilizing inflation than a tightening in the baseline or in *Steep NKPC* scenario (Karadi et al. 2025). We provide some intuition around this result in the next section.

Implications for monetary policy

As discussed so far, in scenarios where a supply-shock is associated with smaller excess supply, monetary policy space is larger, meaning that policy tightening can stabilize both inflation without incurring significant excess supply and output loss. In contrast, central banks could also face scenarios that imply a more difficult trade-off for monetary policy, where to stabilize inflation, the central bank may permit some cost to the real economy. We focus on these more challenging scenarios below.

To gauge how monetary policy can still deliver better outcomes in these scenarios, we quantify the desired values of policy responsiveness Θ_{π} that can minimize the central bank's objective that we postulate to be

$$L = std(\pi_t^{core}) + std(\widetilde{Y}_t) + 0.5std(\Delta R_t). \quad (2)$$

We assume equal weight on the standard deviations of YoY core CPI inflation, π_t^{core} , and output gap, $\widetilde{Y}_t$, and a weight of 0.5 on the volatility of the change in the policy rate, ΔR_t , respectively. These best outcomes are indicated by a Diamond in Chart 3.[15]

We consider two sensitivity analyses where we proxy the flexibility around monetary reaction by varying (i) policy reaction sensitivity to inflation; and (ii) the degree of policy rate smoothing and the horizon over which central bank brings inflation back to the target.

Varying sensitivity to inflation

In both scenarios in **Chart 3**, the best policy option corresponds to a more aggressive policy stance than in the *Shock-prone (Large)* baseline. In the baseline $\Theta_{\pi} = 6.6$, whereas $\Theta_{\pi} = 8.3$ for steeper NKPC, and $\Theta_{\pi} = 13.3$ for de-anchored expectations.

These results show that the outward shifts in policy trade-offs call for a more aggressive policy stance on average. In a more shock-prone economy, the relative frequency of quarters with high inflation (and therefore low sacrifice ratio) is higher. Since in such quarters, tighter monetary policy response is more effective at stabilizing inflation, the best monetary policy would be tighter on average. We can interpret this result as monetary policy having less room to look through inflation fluctuations.

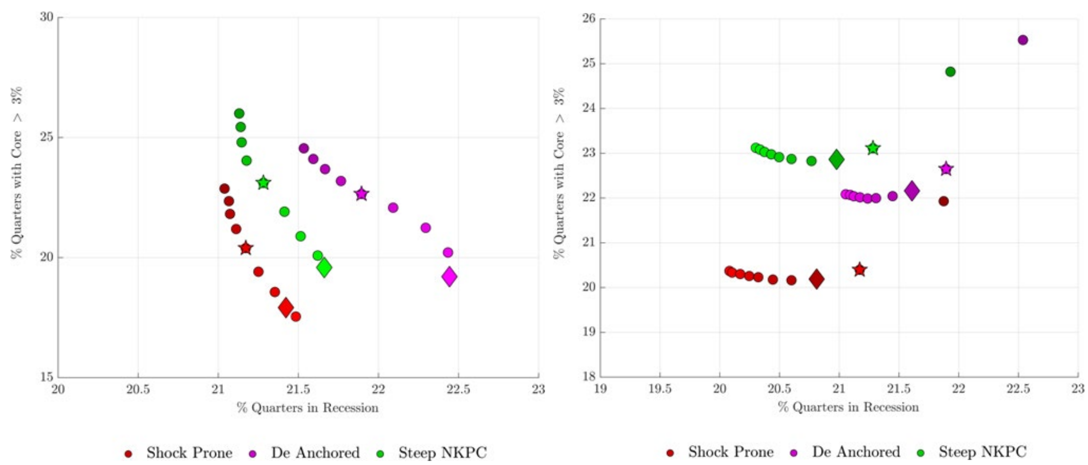
[15] The results are not sensitive to dropping the third (interest rate) term in the objective function, and to using YoY CPI inflation instead of core CPI inflation in the first term.

Furthermore, if the trade-off pivots clockwise—in addition to shifting out—as in the *De-anchored* scenario, the relative frequency of quarters with high inflation (and low sacrifice ratio) is even higher, calling for an even more aggressive policy stance on average.[16]

Varying policy horizon and interest-rate smoothing

We also examined whether varying other parameters of the policy rule (1) can minimize central bank objective loss function in different scenarios.

Chart 4. Varying policy horizon and interest-rate smoothing



a. Varying policy horizon **b. Varying interest rate smoothing**

Notes: Each dot corresponds to average % of quarters with core inflation above 3% (y-axis) and average % of quarters in a recession across 5000 simulations in *Shock-prone (Large)* baseline (brown) and three scenarios. For Panel a, for each baseline and scenario, we repeat simulations varying horizon H in policy rule policy rule (1) from low $H = 0$ to high $H = 8$ (darker dots correspond to higher values). Star denotes the outcomes under historical rule $H = 4$. For Panel b, for each baseline and scenario, we repeat simulations varying the smoothing parameter Θ_R in the policy rule (1) from low $\Theta_R = 0.05$ to high $\Theta_R = 0.95$ (darker dots correspond to higher values). Star denotes the outcomes under historical rule $H = 4$ and $\Theta_R = 0.85$. Diamond denotes the outcomes that minimize central bank's objective function (2).

Chart 4a illustrates the trade-offs when we vary the policy horizon from low $H = 0$ to high $H = 8$ (darker dots correspond to higher values), with star denoting the results for the historical rule with $H = 4$. Shortening the horizon effectively makes the policy stance more aggressive with respect to inflation deviations. Just like with varying inflation coefficient Θ_π

[16] Chart A.1 in the Appendix presents the trade-offs in Charts 1 and 3 expressed in terms of standard deviations of core inflation and output gap. The key conclusions remain the same.

in **Chart 3**, stabilizing inflation with a shorter window comes at a cost of higher incidence of recessions. Simulations also show that shortening the policy horizon improves combination of inflation and output gap in *De-anchored* and *Steep NKPC* scenarios relative to the baseline.[17] This suggests that in response to second-round effects that may amplify inflation risks—via de-anchored inflation expectations or steepening of the Phillips curve—raising interest rates sooner than later may be desirable.

Chart 4b provides the results where we repeat simulations varying the smoothing parameter Θ_R in the policy rule (1). We repeat simulations varying the smoothing parameter from low Θ_R=0.05 to high $\Theta_R = 0.95$, with star denoting the outcomes for the historical rule with $\Theta_R = 0.85$. Across all scenarios, excessive smoothing implies interest rates are very slow to adjust, which increases inflation and output volatility. Reducing the degree of smoothing lowers output gap variation but slightly increases inflation variation. On balance, adjusting the smoothing parameter does not do much to address additional variation in two scenarios relative to the baseline.

Takeaways

Simulations using ToTEM show that a more shock-prone economy—characterized by larger and more frequent supply disturbances—materially changes the inflation–output trade-offs faced by monetary policy. When supply shocks are only moderately larger than in pre-pandemic times, inflation exceeds 3% more often but does not become more persistent, and recession risks increase only slightly. In contrast, very large supply shocks raise both the frequency and persistence of above-target core inflation and significantly increase recession risks, replacing the "divine coincidence" with recurring and costly policy trade-offs. Even aggressive policy rules cannot fully restore the inflation stability observed in normal times without imposing sizable output losses.

The results also highlight how amplification mechanisms—such as a steeper Phillips curve or de-anchored inflation expectations—worsen these trade-offs by increasing inflation volatility and output costs. In such environments, the policy that minimizes macroeconomic volatility is tighter on average than the historical rule, reflecting less scope to look through inflation fluctuations as high-inflation states become more frequent. On the other hand, policy space is larger when supply shocks occur in periods of excess demand or partly reflect declines in potential output. Overall, a shock-prone world implies more frequent policy judgments. To support robust monetary policy, there is heightened value of timely, high-quality supply-side intelligence and improved models featuring

[17] In the model, *H=1* minimizes the objective (2) in the baseline and "Potential fall" scenario, and *H=0* minimizes the objective in De-anchored and Steep NKPC scenarios.

supply side of the economy to inform when and how flexibility is applied within inflation-targeting monetary policy frameworks.

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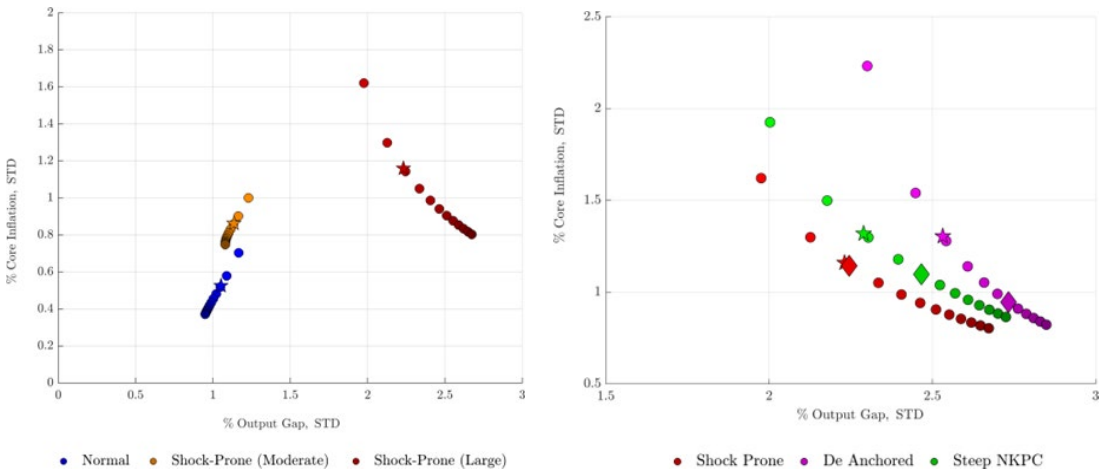
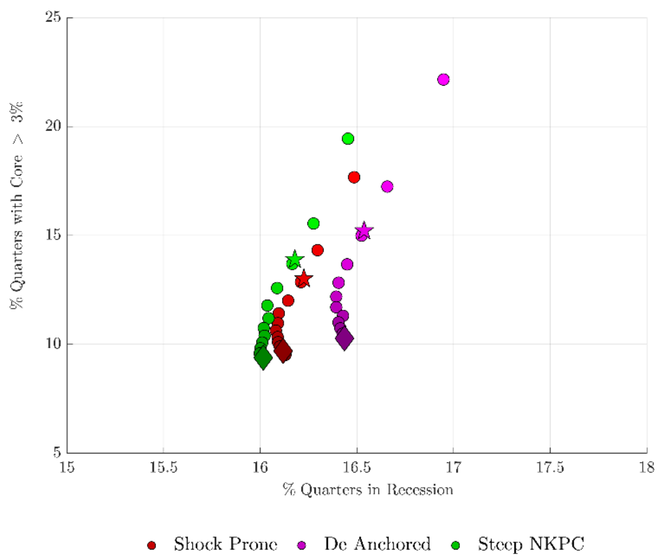
Appendix

Chart A1. Trade-offs expressed using standard deviations



<u>Notes:</u> Each dot corresponds to standard deviation of core inflation, in % (y-axis) and standard deviation of output gap, in %, across 5000 simulations. For the *High Demand* scenario, the inflation and output outcomes are calculated using the subset of quarters from the *Shock-prone (Large)* baseline, discarding quarters with core inflation above 3% and final consumption below the steady state. Star denotes the outcomes under historical rule $\Theta_{\pi} = 4.65$. Diamond denotes the outcomes that minimize central bank's objective function (2).

Chart A2. Scenarios in *Shock-Prone (Moderate)* economy simulations



<u>Notes:</u> Each dot corresponds to average % of quarters with core inflation above 3% (y-axis) and average % of quarters in a recession across 5000 simulations in *Shock-prone (Moderate)* baseline (brown) and two scenarios.