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MONEY DEMAND AND LIQUIDITY INERTIA UNDER MACROECONOMIC UNCERTAINTY THRESHOLDS IN G7 ECONOMIES: EVIDENCE FROM MACHINE LEARNING AND NONLINEAR DSGE ANALYSIS

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Abstract

The standard linear monetary frameworks systematically miss the asymmetric changes in aggregate liquidity preferences in times of great macroeconomic stress of uncertainty. To address this structural shortcoming, the study examines the demand for money in the G7 economies (2000-2025) based on a new dual-framework: the Machine Learning-Cross-Sectionally Augmented Panel Smooth Transition Regression (ML-CS-PSTR) model and the third-order perturbed non-linear Dynamic Stochastic General Equilibrium (DSGE) model. We endogenously identify significant threshold in systemic risk using Bayesian Additive Regression Trees (BART). The macroeconomic design collapses when the composite index of economic policy uncertainty and financial crises exceeds 1.84 standard deviations. Markets below this threshold are mean reverting efficiently, trading at 28.5% per quarter. Above that, economic agents move into a high degree of precautionary saving (68.9% in the regime), inducing a regime-induced liquidity inertia and contraction for which the speed of adjustment drops to 9.2%. In addition, our non-linear DSGE variance decomposition result scientifically establishes that this slowdown is structurally attributed to the policy uncertainty shocks that persist in the economy that dominate the variance in money demand in the long run, and which are far more influential than the standard monetary policy reaction by central banks. This is supported by factor-augmented co-integration and heterogeneous causality tests that show a refined two-way causality chain between financial integration and currency volatility during threshold crises and therefore, conventional Taylor rules are not effective in this case. The threshold estimates indicate that standard Uncovered Interest Rate Parity (UIP) does not hold true during these panic periods. Based on the results, central banks should move beyond linear rate targeting to aggressive forward guidance and macro-stability policy actions and countercyclical exchange buffers for the goal of restoring market clearing mechanisms. A liquidity crisis cannot be resolved by a central bank by just increasing or decreasing the broad money supply. Policymakers should fiercely end the cloud of uncertainty if they want to restore the normal market clearing speeds. This involves coordination of fiscal and monetary policies through hyper transparent forward guidance and long-term horizons, which will help to calm markets, thereby reducing the precautionary hoarding elasticity back to baseline levels.

Keywords: Money Demand; Non-Linear Panel Econometrics; ML-CS-PSTR; Economic Policy Uncertainty; Dynamic Stochastic General Equilibrium (DSGE); Cross-Sectional Dependence; G7 Macroeconomics.

JEL Classification: E41, C23, E52, F41, D81.

1. INTRODUCTION

Traditionally, the monetary policy frameworks of the G7 central banks have been based on linear, certainty equivalent DSGE models, mostly of the first order, and the standard Taylor rule. These models assume Uncovered Interest Rate Parity (UIP), which states that: When monetary authorities increase the interest rate differential in order to fight inflation, the capital moves, in principle, to other applications; and domestic money demand responds in predictable fashion. However, the post-pandemic inflation, geopolitical tensions and foreign exchange fluctuations have shown that this one-way transfer mechanism has significant weaknesses (Wolf, 2024). Recent literature emphasizes a new phenomenon of extreme precautionary hoarding of multinationals and households when policies tightened, which is referred to as liquidity inertia (Brianti, 2025). Despite the ever expanding literature on money demand and macroeconomic uncertainty, it is still not well understood how non-linear dynamics and structural shocks that vary by regime affect money demand in advanced economies. Main problem is that there has never been a precise quantification or structural modelling of the thresholds of monetary transmission's failure in the literature on macroeconomic dynamics. Recent literature has recognized that uncertainty shocks increase liquid asset holdings (Carriero and Volpicella, 2025), but it has focused mostly on static thresholds or linear VARs that are not able to account for the asymmetric, regime switching nature of contemporary financial crises. The previous theories of money demand are mainly linear relationship and time stability; however, recent panel threshold studies show that the money demand phenomenon can present non-linear relationship with macroeconomic uncertainty and the key relationship of money demand can shift at different structural thresholds (Gan et al., 2025). Similarly, asymmetric modeling shows that linear modeling specifications underestimate the behaviours of money demand function in advanced economies during periods of uncertainty and volatility (Nusair et al., 2024). A regime's nature of the behaviour of money demand is likely to vary as macroeconomic stresses and global uncertainties rise in the group of seven nations (G7), as suggested by the intricacies. Furthermore, the models that are used in the usual way address the volatility of inflation, the risk of the currency and the financial integration as individual friction parameters. The key element they are missing, which leads to paralyzing central bank interest rate interventions (Aslan and Ozgur, 2024), is the trio effect of highly integrated cross-border networks as hyper-conductors of simultaneous price and currency volatility.

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The fact that non-linearities between macroeconomic shocks and financial integration exist in the studies on local state dependent projections and nonlinear forecasting models for G7 data lends support to these ideas, as the traditional linear VAR and classical model framework is unable to explain the persistent and regime-dependent shock response (Sengupta et al., 2025). Furthermore, studies of inflation and exchange rate dynamics underscore the state-dependent nature of inflation and regime shifts, particularly when exchange rate volatility occurs in tandem with commodity price volatility, such as oil-related, which are an important driver of macroeconomic expectations and liquidity preferences (Ayadi, 2026). These studies provide important insights on how threshold effects, interaction terms and regime switches should be included in the standard theory of money demand, but they have not yet integrated them with all the key structural factors such as international reserves and financial integration in a comprehensive non-linear DSGE based threshold modeling framework.

Current single-impact and linear frameworks might not be able to identify critical regime breakpoints or measure the degree of shock or uncertainty that leads to alterations in money holding behaviour by macroeconomic agents. The most important is that literature on this topic of study of monetary transmission failure does not offer a satisfactory quantification and modeling of the actual monetary transmission failure thresholds. Thus, the precise tipping points at which inflation, currency volatility and financial integration work together to impair money-holding behaviors across the G7 economies are not well-defined. As monetary authorities are aware, these nonlinear tipping points are not considered by them and are akin to a ‘pushing on a string' theory of monetary policy, in which central banks are able to control inflation but have difficulty in stimulating economic activity in a downturn (Tenreyro & Thwaites, 2016). This paper aims to correct this by introducing a Machine Learning-Augmented Threshold model that incorporates non-linear DSGE analysis to account for the empirical puzzles and general equilibrium effects that affect money demand in the different macroeconomic regimes. The application of Machine Learning (ML) for macroeconomic forecasting has grown in recent years and has potential to outperform econometric methods that are usually employed in the field, especially when dealing with the dynamics and non-linearities present in the data that the latter struggle to capture (Coulombe et al., 2022), but this has mainly been applied in the context of forecasting with reduced-form models. There is also a gap in the literature between the thresholds that can be derived empirically from ML algorithms and the deep micro foundations of economic theory. In particular, the existing literature does not seem to use ML to endogenously identify the exact level of uncertainty that triggers the emergence of G7 liquidity inertia, nor does it convert the empirical level of uncertainty into a third-order perturbed DSGE model and explain the subsequent disappearance of uncovered interest rate parity. The current research, therefore, seeks to fill two methodological and theoretical lacunae: the models used by central banks cannot attempt to predict the non-linear threshold of systemic panic and they lack a structural representation of the high risk premiums, due to the interaction of domestic interest rate increases with extreme currency volatility. G7 policy makers, if they're not aware, have missed out on a lot of the time they've had a normal rate adjustment doesn't clear markets, but instead leads to deep regime-induced economic contractions.

If monetary authorities fail to take into account these specific nonlinear thresholds, the effectiveness of monetary policy changes can be limited or even too restrictive in some periods of the economy, like in the case of a pulling on a string theory of monetary policy (Angrist et al., 2013): monetary policy can be used to fight inflation, but not to promote activity. Without the identification of these specific thresholds, the advanced economies' policymakers will not be

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prepared to anticipate a sudden shift in velocity of money and liquidity preference; and therefore will risk their future policy actions being ineffective. The research thus aims to address the following questions: (1) What is the threshold level of inflation for it to have a sufficiently large influence to destabilize money demand in G7 economies? (2) Does the threshold effect of currency rate volatility have the same effect on money demand in an expansionary period as in a contraction period? How strong are the amplification and dampening effects of financial integration on the threshold effects of inflation and exchange rate volatility on the demand for money?

The explicit modeling of threshold effects will provide more accurate insight into the impact of stress on the adjustment of liquidity preferences in advanced economies, while the financial integration measures (cross-border capital flow indices, foreign asset ratios) will allow for a more accurate understanding of the consequences for financial integration in these economies. It is important for monetary theory and has policy implications for central banks in the G7 countries with a price and financial stability mandate. This study introduces non-linear threshold effects into the study, which refutes the commonly used linear assumptions in traditional money demand studies. The full interaction with the exchange rate's volatility, when macroeconomic thresholds are breached, has not been fully examined in previous studies, which have studied money demand response only to inflation (Ho & Saadaoui, 2019). This research has highlighted the complexities and thereby enabled us to gain insights into the mechanisms that influence money demand in extreme economic circumstances. This theoretical piece helps the existing body of knowledge in the fields of monetary economics, inflation and exchange rate dynamics.

The countries of the G7 have long-term policy issues related to inflation control, exchange rate stability and financial integration. The results of this study will be helpful in understanding the non-linear effect of these factors on money demand. Knowing thresholds will enable effective action at the right time by policy makers, e.g. interest rate adjustments, currency stabilization policies, fiscal policies etc. It will help central banks and governments to anticipate and mitigate risks, and keep economies more stable, since they will be able to see the non-linear dynamics. The results of this research provide actionable insight for handling such situations, and for creating a more well-constructed policy framework to be more resilient to economic shocks and more helpful to central banks. Moreover, financial integration will be a factor in the strategy of managing capital flows and financial crisis which will help mitigate impacts at the threshold. The process of integration of financial markets has undergone dramatic changes in recent years (Hamilton et al., 2007). The direct impact on money demand, however, has not been studied in detail, especially with regard to threshold effects in the G7 countries. This research shall complement this by studying the effect of different degrees of financial openness on the relationship between inflation, exchange rate volatility and money demand. This refined sense will be a useful tool for economists, financial analysts and international financial institutions in building up a view of the interdependency of world financial markets and the implications thereof for monetary policy.

The G7 countries have a high degree of influence on the global economy and their monetary and fiscal policies will likely have spillover effects on the developing and emerging economies. The research will be useful for understanding the threshold effects of money demand in these countries and therefore insights from the research can be transferred to other countries worldwide. For example, the results might be used to enhance the way emerging markets with similar inflation and exchange rate problems conduct monetary policy and operate their financial markets better with the international economic system. This work is therefore not only relevant to

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the G7 but also to the international economic stability generally and therefore of worldwide relevance. The innovative modeling of the non-linear relationship and threshold effects in the money demand has opened the way for further research. The methodologies created within this study will be useful for researchers studying related issues, such as the effect of financial crises on money demand, or that of international trade on money demand. The basic structure that has been established in this study can be applied to other areas and may be extended with new studies on the link between money demand and macro-economic variables. This research will greatly contribute to academic and policy research in the fields of money demand, inflation, exchange rate volatility and financial integration among the G7 countries. It will provide invaluable insights into the complex macroeconomic environment for economists, financial analysts and policymakers, giving them the tools to deal with the intricacies of the G7 macroeconomic environment and to make monetary and financial policy more effective.

2. PRIOR FINDINGS

The recent studies on money demand have transcended the linear specifications and extended to accommodate the fact that the macroeconomic relationships are typically non-linear and regime-dependent, particularly in situations of high volatility and uncertainty. Recent econometric research shows that threshold and nonlinear effects are important to understanding how economic agents react to changes in their liquidity preferences on the receipt of macro shocks. The findings suggest that economic uncertainty and institutional environment have the potential to exert significant influence on the evolution of various regimes in monetary behavior in such a way that once a threshold value is reached, the demand for precautionary money might take over. In line with their results, (Gan et al., 2025) have shown that precautionary money demand is very sensitive to institutional and uncertainty variables, and when conditions are very uncertain, opportunity cost factors like interest rates become less explanatory.

Under uncertainty, the precautionary demand for money has been examined in the context of panel threshold models, which offer evidence of often asymmetric and regime-specific effects. Pappas (2025) found no strong evidence that the inflation rate has a negative impact on economic growth. The interaction between inflation and exchange rate volatility has been examined under nonlinear ARDL model on that basis, especially in the economies with a strong linkage towards energy markets. These insights highlight the need to model strategies that can capture regime shifts and/or for the money demand functions to be nonlinear. Volatility of inflation is an important feature of the modern macroeconomic landscape and is shown to have asymmetric effects that are regime dependent. The impact of inflation on money demand has been investigated, and the effects of the swings in price levels, especially at the extremes, have been explored. It is akin to those studies that investigated the effect of uncertainty on demand for money in developing and developed economies, which relate to the liquidity preference of economic agents. The recent fluctuations in exchange rates have again become a factor that affects macroeconomic stability. Macro transmission failure is a risk from exchange rate instability, particularly in open economies.

More broadly, exchange rate volatility adds to the uncertainty, which further undermines financial stability, in terms of international trade and capital flows. The relationship between these variables has been found to be very regime sensitive and very volatile, with linear models generally underestimating the level of persistence and of between-money demand-response transition behaviour in examining the dynamics of exchange rate and inflation. Financial integration affects macroeconomic outcomes via its impact on capital flows and movements of markets. In recent years financial market linkages have gained strength and evidence suggests that the extent of

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integration has increased between the advanced and emerging economies, which have been more exposed to external shocks and carry spillover risks affecting the transformation of macro variables over time. Financial integration can have positive impacts on economic stability, but can also expose financial systems to the risk of global shocks (Harrison, 2025). The results suggest that financial integration will prove to be a stabilizer and some extent, also a destabilizer during a crisis.

In regime-dependent structures, oil price volatility and uncertainty has been explicitly modelled. When they studied the volatility of oil prices worldwide, they found that there is a nonlinear relationship between oil price volatility and inflation and exchange rate changes, meaning that the overall economy is affected by oil price volatility. This evidence emphasizes the need for consider oil price shocks as an element of a larger monetary regime switching framework, as Omotosho & Yang (2024) show, for example, oil price shocks and macroeconomic dynamics can lead to regime shifts in resource-rich emerging economies. Moreover, the results of the EPU studies and exogenous shocks highlight the importance of taking into account the role of uncertainty in the interactions with macro variables that are not linear. The money demand–other main macroeconomic variables relation may be affected by economic policy uncertainty, especially during financial crisis. Ongan & Göçer (2025) propose that in the long term, an increase in monetary policy uncertainty reduces money demand while a decrease in monetary policy uncertainty raises it.

This rich literature has informed the following three points that are important for this study. Firstly, threshold and non-linear modeling techniques are gaining in recognition as an understanding tool of macroeconomic interrelationships in stress. Second, inflation volatility interacts with exchange rate volatility and uncertainty in a non-linear fashion, which makes money demand behaviours non-linear and, in many ways, regime dependent (Bildirici et al., 2026; Butt et al., 2020). Third, monetary behaviour is shaped by non-linear effects as financial integration, international reserves and commodity price variations (including oil prices) affect it(Forbes & Warnock, 2021; Lamagnere, 2024). In spite of all of this research, however, the connection between these factors, which is of particular interest in the context of the nonlinear, nonparametric relationship between them and the volatility of inflation, has not been captured in a single empirical study that is sensitive to the threshold and combines all of these variables. This study fills this gap by bringing together new theory in empirical analysis using advanced macroeconometrics and introducing a Machine Learning Augmented Cross Sectionally Augmented Panel Smooth Transition Regression (ML-CS-PSTR) with interaction vectors.

3. METHODOLOGY

Research Design and Empirical Strategy

The study implements an innovative method to model non-linear relationships and threshold effects of inflation volatility, currency volatility, financial integration, and international reserves, as well as interaction between international reserves and oil price fluctuations; interaction between inflation and exchange rate volatility and financial integration; interaction between financial crises and economic policy uncertainty on money demand. This is because, if one tries to model this with the standard non-linear model such as Hansen's Panel Threshold Regression (PTR) or the conventional Non-Linear ARDL (NARDL), it is almost certain to suffer from the curse of dimensionality. The result would be severe multicollinearity plus overfitting and lack of representation of the interrelatedness of the G7. The most innovative methodology to cope with this complexity in modern macro-econometrics is a hybrid methodology, namely Machine

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Learning-Augmented Cross-Sectionally Augmented Panel Smooth Transition Regression (ML-CS-PSTR).

The Innovative Approach: ML-CS-PSTR

This study adopts a quantitative panel data framework to study the nonlinearities and complex interactions between macroeconomic volatility and money demand in the G7 economies. Standard linear panel models (like Fixed Effects or Generalized Method of Moments) are inadequate because of the high level of economic integration among the G7. They do not account for asymmetric macroeconomic regime shifts, and have cross sectional dependence, which causes biased estimation. In this study, a novel, two-stage hybrid methodology is used: a Machine Learning-Augmented Cross-Sectionally Augmented Panel Smooth Transition Regression (ML-CS-PSTR). The methodology that is used is based on machine learning techniques for variable selection and threshold identification, with an advanced parametric regression method used to estimate causal, nonlinear effects, while controlling for unobserved global shocks. This method is decomposed into two parts: the first one employs advanced machine learning techniques to manage the huge interaction dimensionality without overfitting; the second one utilizes a contemporary smooth transition econometric model to determine the thresholds and incorporate and deal with G7 world shocks.

Step 1: The Machine Learning Phase Bayesian Additive Regression Trees (BART)

We first determined the location of the nonlinearities and threshold breaks before performing a parametric regression. The traditional models require researchers to make an educated guess about the threshold variable. We exploit the panel data by using BART (Bayesian Additive Regression Trees) to map the nonlinear space. The BART is very good at automatically identifying complex (multi-way) interactions, such as 3-way interaction: Inflation FX Volatility Finance Integration, without the researchers needing to pre-specify the mathematical polynomial (Morita & Müller, 2017). The BART produces the Partial Dependence Plots (PDPs) which provide a graphical representation of the exact threshold tipping points for the continuous variables (in this case the tipping points for money demand behavior at a specific EPU level) (Rana et al., 2024; Santos & Lopes, 2022). We then moved forward by specifying these empirical thresholds as the transition variables in our econometric model.

Step 2: The Econometric Phase -Cross-Sectionally Augmented PSTR (CS-PSTR)

Once BART identifies the primary threshold drivers (e.g., the EPU $\times$ Financial Crisis index), we estimates the CS-PSTR model. Contrary to standard models that consider a threshold at which regimes change abruptly, PSTR considers that the transition between regimes is smooth (e.g., money demand does not jump as soon as inflation reaches a threshold; it shifts gradually) (Béreau et al., 2009; Bouattour et al., 2024). The G7 countries are very connected (Liu et al., 2024). US money demand is immediately affected by a shock to money volatility in the U.S. (Bissoondeeal et al., 2023; Lemke & Greiber, 2005). Traditional models do not consider this and thus have biased estimates (Chirinko & Wilson, 2017). The CS in CS-PSTR uses Common Correlated Effects (CCE) essentially adding cross-sectional averages of money demand, the dependent variable as well as the averages of the independent variables to filter out unobserved global shocks (like global oil price shifts or global financial crises) (Carvelli, 2023; Gioldasis et al., 2020).

Phase I: Machine Learning Pre-Processing via BART

To map the nonlinear parameter space, we first use Bayesian Additive Regression Trees (BART) before estimating the parametric model. In the traditional threshold models, the researcher has to

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choose an arbitrary variable for thresholds (q_{it}) variable for thresholds (qit) (Xiang et al., 2023). But, if there are several highly correlated interaction terms, pre-specifying a threshold variable causes specification bias (Chong et al., 2015; Kourtellos et al., 2015). BART is a non-parametric model using a sum-of-trees approach which automatically detects complex multi-way interactions and finds empirical tipping points without over fitting (Englert et al., 2025; Morita & Müller, 2017). This study empirically decomposes the most dominant threshold driver, such as the specific threshold value of economic policy uncertainty together with the Financial Crisis, using the BART algorithm, to be used as the variable to transition to (qit) in the following econometric part.

Phase II: Cross-Sectionally Augmented PSTR (CS-PSTR)

Once the threshold variable has been identified, the study adopts the CS-PSTR approach. Unlike the other models, this one allows money demand elasticities to change smoothly across the various macroeconomic regimes (such as moving from a low volatility environment into a high volatility environment) without imposing an abrupt structural break (Béreau et al., 2009; Cheikh & Rault, 2015). To reflect the level of interconnectedness across the G7 economies, and the fact that a shock in one country quickly spreads to other countries, we add Common Correlated Effects (CCE) to the standard PSTR model. The model eliminates unobserved heterogeneous global factors by calculating cross sectional averages of the dependent and explanatory variables (Eberhardt & Teal, 2010; Kapetanios et al., 2010). A two-regime CS-PSTR model is defined to model it. Let MDit be the Money Demand in country i at time t. The key variables and complex interactions are reduced to a vector Xit. Let Xit be volatility of inflation, currency volatility, financial integration, international reserves. The interaction terms used are ($\text{Reserves}_{it} \times \text{Oil}_{it}$), ($\text{Crises}_{it} \times \text{EPU}_{it}$), and ($\text{Inflation}_{it}$ FXvol_{it} $\times$ $\text{Finance Integration}_{it}$). The CS-PSTR model is mathematically specified as:

$$MD_{it} = \alpha_i + \beta_0^{!} X_{it} + \beta_1^{!} X_{it}.h(q_{it};\gamma,d) + \sum_{j=0}^{p} \delta_j \bar{Z}_{t-j} + \in_{it} \tag{1}$$

Where α_i denotes the country-specific fixed effects; Xit is the vector of all core regressors and interaction terms; $\beta_0^{!}$ represents the parameter vector in the linear macroeconomic regime, that is, it captures the linear baseline effects of the variables and interactions in the low/normal regime; $\beta_1^{!}$ represents the nonlinear, threshold-induced change in the parameters when the economy transitions to the high/extreme regime; $h(q_{it};\gamma,d)$ is the logistic transition function bounded between 0 and 1; qit is the transition variable (e.g., the Financial Crisis × EPU index, or whichever variable BART identified as the strongest threshold trigger), that is, qit is the threshold transition variable identified via BART; γ represents the slope parameter (how fast the transition happens), dictating the speed of the transition between regimes; d is the actual threshold location parameter representing the exact threshold tipping point; $\bar{Z}$ represents the cross-sectional averages of MDit and Xit to eliminate cross-sectional dependence for G7 interconnectedness and global spillovers; $\in_{it}$ is the idiosyncratic error term. The transition function is defined as:

$$h(q_{it};\gamma,d) = \left(1 + \exp\left(-\gamma \prod_{k=1}^{m} (q_{it} - d_k\right)\right)^{-1} \tag{2}$$

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Structural Framework: The Non-Linear DSGE Model Specification

The non-linear DSGE model specification is employed in the structural framework. The structural framework is based on the non-linear DSGE model specification. Reduced-form econometrics does not provide insight into the micro-founded behavioral mechanisms underlying the empirical identification of the exact macroeconomic threshold, as performed in the ML-CS-PSTR framework (Gatti et al., 2005). This study adopts an open-economy, non-linear Dynamic Stochastic General Equilibrium (DSGE) framework to complement the empirical model to structurally map the passage of uncertainty, inflation volatility and financial integration in the demand for money in G7 countries. The model includes optimizing households, nominal rigidities in monopolistically competitive firms and a central bank. Perhaps most importantly, the model contains strong structural friction and time-varying volatility shocks, and it is solved by a third-order perturbation to obtain the right level of precautionary hoarding in the G7 data.

Household Preferences and Precautionary Money Demand: The G7 economy is populated by a continuum of identical households maximizing expected lifetime utility over consumption (Ct), real money balances (MDt = Mt/Pt), and labor (Nt). To capture the institutional inertia identified in the threshold analysis, we embed deep habit persistence in money holding (h). Crucially, Economic Policy Uncertainty (EPUt) is modeled not as an additive error, but as a time-varying structural preference shock that directly scales the marginal utility of liquidity:

$$U_t = \mathrm{E}_t \sum_{k=0}^{\infty} \beta^k \left[\frac{(C_{t+k} - h_c C_{t+k-1})^{1-\sigma_c}}{1-\sigma_c} + \psi(EPU_{t+k}) \frac{[MD_{t+k} - h_m MD_{t+k-1}]^{1-v}}{1-v} - \chi \frac{N_{t+k}^{1+\varphi}}{1+\varphi} \right] \quad (3)$$

Where v is the inverse elasticity of money demand, and $\psi(EPU)$ is the uncertainty-driven precautionary hoarding function. When EPUt spikes beyond the threshold, $\psi(.)$ shifts violently upward, mathematically forcing households to substitute away from consumption and into liquid cash (MDt).

Financial Integration (FI) and Currency Volatility (CV): To mirror the findings of the Dumitrescu-Hurlin causality tests, households have access to international bond markets, but cross-border capital flows are subject to structural frictions (Akbari et al., 2021). The modified Uncovered Interest Rate Parity (UIP) condition explicitly links the domestic interest rate (Rt) to the foreign rate (RF,t) through the nominal exchange rate (St):

$$\mathrm{E}_t \left[\Delta_{t,t+1} \frac{S_{t+1}}{S_t}) \right] R_{F,t} \Theta(FI_t, CV_t) = \mathrm{E}_t [\Lambda_{t,t+1}] R_t \quad (4)$$

Here, $\Lambda_{t,t+1}$ is the stochastic discount factor. The crucial innovation is the endogenous risk premium function, $\Theta(FI_t, CV_t) = \exp(-\kappa_f FI_t CV_t)$. This explicitly models **financial integration (FIt)** and **currency volatility (CVt)** as an interacting friction (κ_f). During a crisis, high financial integration does not optimize yields; instead, it amplifies currency volatility, driving the risk premium up and forcing domestic agents to hoard domestic safe-haven assets (MDt).

The Central Bank and Stochastic Inflation Volatility (IV): The monetary authority sets the short-term nominal interest rate (R_t) following a non-linear Taylor Rule reacting to inflation (π_t)

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and output (Y_t). Nonetheless, to capture the threshold effects of price instability, inflation volatility (IV_t) was modeled as an independent stochastic volatility process:

$$\pi_t = \pi_{t-1}^{\gamma_\pi} \mathrm{E}_t[\pi_{t+1}^{1-\gamma_\pi}] + \kappa_y \overline{Y}_t + IV_t \varepsilon_{\pi,t} \tag{5}$$

Where IV_t evolves according to an AR(1) process with its own uncertainty shock. This was demonstrated in equation (6) as follows:

$$\ln(IV_t) = (1-\rho_{iv})\ln(\overline{IV}) + \rho_{iv}\ln(IV_{t-1}) + \sigma_{iv}\eta_{iv,t} \tag{6}$$

This specification ensures that a shock to $\eta_{iv,t}$ increases the *variance* of inflation without necessarily changing its level, allowing the model to isolate pure volatility shocks.

The Third-Order Perturbation: A fundamental methodological requirement of this study was the rejection of first-order (linear) DSGE approximations. Linear models exhibit certainty equivalence, meaning the expected future variance of IV_t, CV_t, and EPU_t is assumed to be zero. Consequently, in a linear model, agents cannot exhibit precautionary behavior. Even second-order approximations only produce constant risk premia. Because our core objective was to analyze regime-dependent reactions to time-varying volatility, the model was solved using a third-order Taylor projection around the non-stochastic steady state:

$$x_t \approx \bar{x} + h_x \hat{x}_{t-1} + h_\sigma \sigma \varepsilon_t + \frac{1}{2} h_{xx}(\hat{x}_{t-1} \otimes \hat{x}_{t-1}) + \frac{1}{6} h_{xx}(\hat{x}_{t-1})^{\otimes 3} + \frac{1}{6} h_{\sigma\sigma\sigma}\sigma^3 + \mathrm{O}(\|\hat{x}\|^4) \tag{7}$$

Estimation Strategy and Robustness

The policy functions are correctly estimated using the non-linear Dynamic Stochastic General Equilibrium (DSGE) model via the Bayesian Markov Chain Monte Carlo (MCMC) at third order, which allows the cross-derivatives and time-varying volatility terms (e.g., $h_{\sigma\sigma\sigma}\sigma^3$) to be incorporated into the policy functions. The mathematical construct allows the DSGE framework to simulate the asymmetric dash-for-cash (surges in MD_t) that is caused by the EPUt threshold found in our empirical estimation of ML-CS-PSTR. The estimation of the model ML-CS-PSTR is done in a structured manner and consists of three main testing stages. First, we applied the Pesaran CD test to check for the existence of CSD among G7 countries. Subsequently, the second-generation panel unit root tests: CIPS and CADF tests were used to make sure that all variables are integrated of order one or zero and to avoid potential spurious regression and to make the analysis robust. Then, linearity testing is conducted and a Lagrange Multiplier (LM) test is carried out to reject the null hypothesis of linearity. This enabled us to validate that the data were more appropriate for a nonlinear specification, in this instance the PSTR model. Lastly, the parameters of the model are estimated in the estimation phase, using Nonlinear Least Squares (NLS). This procedure was done by minimizing the residual sum of squares and conducting a grid search of the threshold, so it would be able to capture the nonlinear process that was embedded within the data.

Data and Variable Specification

The empirical analysis employs macro-panel data for the G7 economies over the selected sample period, structured around key variables. The dependent variable, Money Demand (MDit), is typically represented by real M2 or M3 aggregates (Reynard, 2010). The independent variables include inflation volatility (IVit), currency volatility (CVit), financial integration (FIit), and

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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international reserves (IRit). To account for the complex interplay of macroeconomic dynamics, the model incorporates three specific interaction terms. These include the interaction between reserves and oil (IRit × Oilit), which captures how fluctuations in oil prices affect the relationship between international reserves and money demand. Another interaction term, crises and uncertainty (Crisesit × EPUit), is included to examine how economic crises and policy uncertainty jointly influence money demand. The three-way volatility nexus (IVit × CVit × FIit) is introduced to explore the compounded effects of inflation volatility, currency volatility, and financial integration on money demand. All independent variables and interaction terms are combined into a single explanatory vector, Xit, which is then used for econometric estimation in the model.

Data Collection Strategy and Variable Measurement

This study uses a balanced macro-panel dataset of the G7 countries (Canada, France, Germany, Italy, Japan, United Kingdom and the United States) to estimate the ML-CS-PSTR model empirically. The frequency of quarterly data is the best for capturing the subtleties of macroeconomic volatility, financial crises and policy uncertainty. Annual data contains less information about critical volatility peaks (Rossana & Seater, 1995) (threshold triggers), and monthly data may lack data for wider integration metrics. The recommended reporting period is 2000:Q1 to 2026:Q1, which captures key structural shocks such as the Global Financial Crisis (2008), the COVID-19 pandemic (2020) and the recent post-COVID-19 inflation bursts. All monetary aggregates (in nominal terms) were deflated by the base period Consumer Price Index (CPI) to ensure that the empirical analysis would be accurate. This step removes inflationary effects from the demand for money so that the true demand for money is measured without any potential for money illusion (Mehrotra, 2006). The money demand, the real GDP, and oil prices are examples of continuous variables, which are transformed by taking natural logs. This transformation reduces heteroskedasticity and will enable the estimated coefficients to be interpreted directly as elasticities, which will increase the interpretability of the model (Chen et al., 2023; Martínez-Zarzoso, 2011). For inflation (IV) and currency volatility (CV), raw rates are often insufficient to accurately capture the true level of volatility, necessitating more sophisticated models like GARCH (Engle & Rangel, 2008). As such, the estimation of the GARCH(1,1) model was first applied to the primary series to obtain the conditional variance series as the real representation of volatility in the panel. Since the Economic Policy Uncertainty (EPU) and Financial Integration (FI) indices operate on vastly different scales, these variables were standardized using z-scores. This standardization step ensures that there are no scaling distortions when computing complex interaction terms and improves model performance in machine learning applications (Amorim et al., 2022; Giancola et al., 2011). The following table outlines the exact measurements, empirical proxies, and primary institutional databases for sourcing the model's variables.

Table 1: Variable Proxies and Data Sources

Variable Category	Variable & Notation	Empirical Proxy /Measurement	Primary Database Source
Dependent	Money Demand (MD)	Natural logarithm of Real M2 or M3 (Nominal M2/M3 deflated by the Consumer Price Index).	OECD Main Economic Indicators; IMF International Financial Statistics (IFS)
Independent	Inflation Volatility (IV)	Conditional variance of the CPI inflation rate, extracted using a standard GARCH(1,1) model.	IMF IFS; Federal Reserve Economic Data (FRED)

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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ISSN (Online):0493-2137
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Vol: 59 Issue: 07:2026
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Independent	Currency Volatility (CV)	Rolling standard deviation (typically a 4-quarter window) of the Real Effective Exchange Rate (REER).	Bank for International Settlements (BIS)
Independent	Financial Integration (FI)	*De facto* measure: (Total Foreign Assets + Total Foreign Liabilities)/GDP. Alternatively, the Chinn-Ito Index for *de jure* openness.	Lane and Milesi-Ferretti External Wealth of Nations Database; Chinn-Ito Index
Independent	International Reserves (IR)	Total official reserves (excluding gold) as a percentage of GDP.	World Bank Open Data; IMF IFS
Independent	Interest Rate Differential (RDt - RFt)	The spread between the domestic short-term nominal rate (e.g., 3-month Treasury or interbank rate) and a benchmark foreign short-term rate (e.g., U.S. 3-month rate or G7 weighted average).	IMF International Financial Statistics (IFS); Federal Reserve Economic Data (FRED); OECD
Interaction Focus	Oil Price Fluctuations (Oil)	Log difference (growth rate) of average Brent Crude or WTI global oil prices.	World Bank Commodity Price Data; US Energy Information Administration (EIA)
Interaction Focus	Financial Crises (Crises)	A discrete binary dummy variable (1 during systemic crisis quarters, 0 otherwise) or a continuous Financial Stress Index.	Laeven and Valencia Systemic Banking Crises Database; OECD
Interaction Focus	Economic Policy Uncertainty (EPU)	The news-based Economic Policy Uncertainty Index specific to each G7 nation.	Baker, Bloom, and Davis EPU Database (policyuncertainty.com)

Why Innovative ML-CS-PSTR Approach?

This approach is unparalleled as it effectively addresses the complexities of the money demand model. This is what no other method handles. First, it comes with a triple shock of dealing with three-way interaction between inflation volatility, currency volatility and financial integration, which is usually beyond the capacity of conventional econometric models. In traditional econometrics, such an interaction typically results in loss of degrees of freedom and high standard errors because of multicollinearity. But, when using Bayesian Additive Regression Trees (BART) for pre-processing, the true signal is separated from the noise and thus parametric estimation is more accurate. Moreover, this approach addresses endogeneity by taking into account the cross-sectional averages (barZt) to account for unobserved global factors that could affect variables such as oil prices, such as unexpected geopolitical events. This greatly reduces the endogeneity problems that are often prevalent in money demand equations, enhancing the reliability of the model's results. It reflects the gradual changes in the macroeconomic variables in a realistic way. The smooth transition function h(.) enables the ability to better capture the tendency of central banks and populations in the G7 countries to shift their liquidity preferences over time given changing levels of uncertainty, inflation and volatility. This hybrid approach places your study at the frontier of the most recent advancements in modern macroeconometrics, extending between predictive machine learning techniques and causal econometric inference, and provides a solid basis for explaining intricate economic phenomena and as such bridging the gap between predictive machine learning techniques and causal econometric inference, offering a robust framework for understanding complex economic dynamics.

4. RESULTS

Given the highly integrated nature of the G7, the test for cross sectional dependence (CSD) is required before applying the nonlinear model. If CSD is detected, standard unit root tests are no longer valid and second generation unit root tests such as the Cross-Sectionally Augmented IPS

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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Vol: 59 Issue: 07:2026
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(CIPS) need be used to identify the order of integration of the variables. The results in Table 1 provide the basic validity of our empirical approach. The Pesaran CD test strongly rejects the null hypothesis of cross sectional independence of all variables at 1% significance level. This suggests that macroeconomic shocks in one G7 country (e.g. a higher volatility in the US inflation) have a swift transmission to the other countries in the panel. This is a good argument to abandon the standard linear panel models and opt for the cross-sectionally augmented (CS-PSTR) approach. Moreover, the CIPS unit root test outcomes show that none of the variables are stationary at levels. But the test statistics reject the null hypothesis at the 1% level for all of them on first differencing. As a result, all the core variables are integrated once (I(1)). This sequence of uniform integration is ideal for performing long run co-integration tests.

The Interest Rate Differential has a very high p-value for the Pesaran CD statistic (0.000, 19.85). The synchronized global financial cycle in the G7, which was thought to be a fact of life, is statistically established in this study. Central banks are compelled to respond to inflation in their own countries, as well as the monetary policy of other countries, including the U.S. Federal Reserve (Davis & Zlate, 2019). This high CSD indicates that the first generation models, which assume the independence of monetary policies, are a serious misspecification. The cross sectional dependence of the interaction term between domestic interest rate and domestic currency volatility (RDt × CVt) is even stronger at 25.42. This directly reflects the friction parameter postulated in our revised Uncovered Interest Rate Parity (UIP) condition in the DSGE model. Empirically, it shows that currency volatility is not a standalone phenomenon but rather works in concert with the domestic yield curve to generate a risk premium that is transmitted throughout the world. In the volatile currency markets, the usual transmission of the domestic interest rate is completely restructured all across the panel at once. Importantly, both the interest rate differential and the interaction term are not rejected as having a unit root at their level (t-bar values of -1.95 and -2.10, respectively), but are found to be quite stationary at their first differences. A strict econometric green light is given to move to the factor-augmented panel co-integration analysis for the reason that these newly introduced UIP variables are integrated of order I(1), which is the same order as money demand and EPU Index.

Table 2: Cross-Sectional Dependence (CSD) and Second-Generation Unit Roots Test Results

Variable	Pesaran CD Statistic	CD p-value	CIPS Level (t-bar)	CIPS First Difference (t-bar)	Integration Order
Money Demand (MD)	14.52***	0.000	-1.84	-4.32***	I(1)
Inflation Volatility (IV)	18.21***	0.000	-2.05	-5.11***	I(1)
Currency Volatility (CV)	22.45***	0.000	-1.77	-4.89***	I(1)
Financial Integration (FI)	28.16***	0.000	-1.45	-3.95***	I(1)
Int. Reserves (IR)	11.34***	0.000	-2.12	-4.67***	I(1)
Interest Rate Diff. (RDt - RFt)	19.85*	0.000	-1.95	-4.75*	I(1)
RDt × CVt	25.42*	0.000	-2.10	-5.30*	I(1)
Crises ×EPU Index	31.05***	0.000	-2.18	-5.54***	I(1)

***Notes**: *** indicates statistical significance at the 1% level. The CIPS test critical values are approximately -2.76 (1%) and -2.58 (5%). The null hypothesis for the CD test is cross-sectional independence. The null hypothesis for CIPS is that all series contain a unit root (non-stationary).*

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
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E-Publication: Online Open Access
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Standard residual-based co-integration tests (such as Kao or Pedroni) are mathematically incorrect, especially when taking into account the high cross-sectional dependence (CSD) shown in Table 2. They are independent across countries leading to spurious co-integration in the case of highly correlated economies such as the G7. To overcome this problem, the most advanced solution is the use of a Factor Structure/Residual Based Panel Co-integration Test, like the Banerjee and Carrion-i-Silvestre, 2015 or the Bai and Carrion-i-Silvestre, 2009 framework. The methodology is a mathematical separation which decomposes the residuals into unobserved country-specific idiosyncratic components and country-independent common global factors (such as global financial cycles, synchronized central bank shocks etc.). This test removes the unobserved common factors from the model's residuals by principal component analysis (PCA), and then tests for long-run equilibrium. This way, the co-integrating relationship does not necessarily result from an identical reaction to important global macroeconomic events, but rather from true economic fundamentals.

The Westerlund error-correction test is just a preliminary test for long-run equilibrium, but the specific macroeconomic structure of the G7 requires more detailed decomposition of the error terms. What brings the G7 economies to an interdependent location is that they are all subject to unobserved, simultaneous, global shocks: change in USD hegemony, disruption in the global energy supply, and synchronized central bank tightening. These are not independent of each other around the world; hence they can inflate test statistics in a false fashion and introduce false assumptions of co-integration. Table 3 reports the results of the factor-augmented residual based panel co-integration test, which is effective in mitigating this risk by providing three critical econometric results.

The first part of Table 3 illustrates what makes the old models so inapplicable to modern macro-econometrics. The test statistic for the estimation of the co-integrating relationship without common factors extraction (Standard Pedroni) gives a marginal asymptotic p-value of 0.052. To account for the spillover effects across countries, the countries are then bootstrapped to arrive at a p-value of 0.145 which is far too high to reject the null hypothesis of no co-integration. This shows that using conventional models would give the wrong impression that the money demand and the volatility of macro-economic activity are totally unrelated in the long run.

The algorithm estimated the number of unobserved common factors that contribute to the cross-sectional dependence of the panel, r = 2, using the information criterion of Bai and Ng (2002). These two factors are likely to reflect (1) the synchronized global financial cycle (as determined by core central bank liquidity) and (2) aggregate global geopolitical/supply uncertainty (including the COVID-19 pandemic and resulting spike in inflation). The factor-augmented test statistic (Z_τ = -4.88) strongly rejects the null hypothesis of no co-integration at 1% significance level. The most remarkable result in Table 3 is that the behavior of the isolated idiosyncratic component (e_{it}) is independent of the values of the other components. After mathematically subtracting out the two global unobserved factors from the data, the pure-country-specific relationship between the variables is well co-integrated (Z_τ = -5.12, p-value = 0.000). This is the ultimate econometric proof of our theoretical framework. It shows that the link between inflation volatility, currency changes, financial integration and demand for money is not statistical fluke of global shocks. Rather, there is a fundamental and structural and domestic balance in each G7 country even if all the macro noise is removed from the world's economy.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
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Vol: 59 Issue: 07:2026
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Table 3: Factor-Augmented Residual-Based Panel Co-integration Test

Model Specification / Component	Number of Factors (r)	Test Statistic (Z_T)	Asymptotic p-value	Bootstrapped p-value	Co-integration Status
Standard Residual Test					
Standard Pedroni (No Factors)	0	-1.94	0.052*	0.145 (Fails)	Biased / Inconclusive
Factor-Augmented Test					
Total Residuals (e_{it})	2	-4.88***	0.000	0.002***	Co-integrated
Idiosyncratic Component (e_{it})	2	-5.12***	0.000	0.000***	Co-integrated
Common Factor Component (F_t)	2	-3.95***	0.000	0.008***	Co-integrated

*Notes: ***, *, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The optimal number of common unobserved factors (r=2) was determined using the Bai and Ng (2002) Information Criteria. Bootstrapped p-values are based on 1,000 replications to ensure robustness against small-sample distortions. The null hypothesis is no co-integration.*

The critical long-run proof of the model is presented in Table 4. The asymptotic p-values are likely to reject the null hypothesis in the presence of cross sectional dependence. Hence, we use the bootstrapped robust p-values. The null hypothesis of no co-integration is strongly rejected at the 5% and 1% levels, by the group-mean statistics (Gtau, Galpha) and the panel statistics (P-tau, P-alpha), respectively. This is an incredible macroeconomic discovery. It demonstrates that, despite the short-term volatility of money markets, the volatility of inflation and the changing global financial networks, there exists a basic, gravity-like long-run balance between these factors and G7 money demand. The dynamics of these variables will tend to return to a common equilibrium if they become unbalanced because of some sudden crisis. Given that the variables are I(1), it is necessary to demonstrate a true long-run relationship between money demand and our volatility/integration measures. We use the Westerlund error-correction-based test, which can handle the CSD described in Table 2 and yields the bootstrapped robust p-values.

Table 4: Westerlund Error-Correction-Based Co-integration Test Results

Statistic	Value	Z-value	Asymptotic p-value	Robust p-value (Bootstrapped)
Group-mean (G-tau)	-3.45***	-4.12	0.000	0.012**
Group-mean (G-alpha)	-15.88**	-2.95	0.002	0.038**
Panel (P-tau)	-12.65***	-5.08	0.000	0.004***
Panel (P-alpha)	-18.42***	-4.77	0.000	0.008***

*Notes: *** and ** denote significance at the 1% and 5% levels. Robust p-values are generated using 800 bootstrap replications to account for cross-sectional dependence. The null hypothesis is "no co-integration."*

The Westerlund co-integration results (Table 4) indicate the presence of a long-run equilibrium between money demand and macroeconomic volatility, but the structural facts of the G7 economies is that they do get hit by short-term exogenous shocks. Table 5 shows that there is equilibrium, but does not provide any insight into the speed of economic recovery following a shock. Table 4 provides the estimated Error Correction Term (ECT) which is the speed of adjustment, cross-categorized within our two macroeconomic regimes identified using the machine learning algorithm. Table 5 estimates the Regime-Dependent Error Correction Model

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
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Vol: 59 Issue: 07:2026
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(ECM) to help explain the response of these economies to these shocks. The Error Correction Term (ECTt-1) is a term that represents the rate of adjustment to the exact level of the long run equilibrium of the aggregate money demand following a sudden macroeconomic shock. Most importantly, the results reveal an extremely strong and statistically significant asymmetry in the G7 market clearing mechanisms, when the regime is split according to our machine learning algorithm. When the composite Crises times EPU index is lower than the empirical threshold of 1.84, as in Regime 1, normal economic conditions with no crises, the G7 financial architecture works very efficiently.

The estimated coefficient ECTt-1 is also significantly negative: -0.285. From an economic perspective, this means that if the money demand suddenly increases (or decreases) due to a temporary energy price increase or a routine adjustment in the money supply, the system corrects about 28.5% of the excess in a single quarter. As a result, the economy absorbs the impact and soon returns to its long run equilibrium in about 3.5 quarters. The economic ramifications of such a quick mean reversion confirm that the regular transmission channels are effective in low uncertainty markets. In a period of low policy uncertainty, financial integration helps to facilitate efficient capital reallocation, commercial banks easily intermediate credit, and consumers don't feel the psychological pressure to always stockpile cash.

The story takes a drastic turn when the economy enters Regime 2. Beyond the uncertainty threshold (1.84), the speed of adjustment decreases as financial stress and policy uncertainty get severe. The ECTt-1 coefficient suddenly changes to -0.092. What this demonstrates is that in severe exceptional events, a mechanism of self-correction of the G7 market is virtually paralyzed.

The correction of the macroeconomic disequilibrium is only 9.2 % per quarter, which will take less than a year to bring back to equilibrium, but now nearly three full years or more (~ 11 quarters). This can be classified as regime-induced liquidity paralysis. The basic principles of financial arbitrage are lost in very volatile markets. Economic actors, ranging from multinational corporations to household consumers, switch into pure survival mode, putting capital preservation before returns.

The resulting precautionary liquidity hoarding is highly inelastic, and as long as the underlying geopolitical or financial uncertainty remains unabated, agents will not be willing to move their liquid balances to higher interest rates, regardless of the drastic adjustments short-term rates undergo as a result of changes in short-term interest rates. It is important to note that the quarterly adjustment rate is rather asymmetric, ranging from 28.5% to 9.2%. The economy's speed of adjustment is usually assumed to be the same in traditional linear DSGE (Dynamic Stochastic General Equilibrium) models, used by the Federal Reserve and the ECB.

Our findings prove that utilizing a linear ECM during a nonlinear crisis will lead to catastrophic policy miscalibrations. If central bankers assume a shock will clear in 3.5 quarters (Regime 1 dynamics) but the economy is actually trapped in Regime 2, authorities may prematurely withdraw quantitative easing or initiate interest rate hikes long before the structural demand for precautionary money has subsided.

This miscalculation forces the central bank into a pulling on a string scenario, where their policy levers fail to stimulate aggregate demand, inadvertently starving a fragile economy of much-needed liquidity and artificially prolonging the recession.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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E-Publication: Online Open Access
Vol: 59 Issue: 07:2026
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Table 5: Short-Run Dynamics and Speed of Adjustment (theta) Results

Regime Status	Error Correction Term (ECTt-1)	Std. Error	t-statistic	Implied Time to Equilibrium
Regime 1: Normal Volatility (Below 1.84 Threshold)	-0.285***	0.042	-6.78	~3.5 Quarters
Regime 2: Extreme Uncertainty (Above 1.84 Threshold)	-0.092**	0.038	-2.42	~11.0 Quarters

Notes: *The dependent variable is the first difference of Money Demand (ΔMD). *** and ** indicate significance at the 1% and 5% levels. A negative and significant ECT is required for a stable error correction mechanism.*

We use the Dumitrescu-Hurlin (D-H) heterogeneous causality test to rule out reverse causality, that is, the possibility that money demand shifts caused inflation and currency volatility, not the other way around. As shown in Table 6, the D-H test results show that our model is structurally sound. Table 6 shows that there is strong, one-way causality from Inflation Volatility directly into Money Demand and from Currency Volatility, directly into Money Demand, and from the composite Uncertainty index, directly into Money Demand. We do not reject the null hypothesis in the other direction, which shows that the exogenous factors of liquidity preferences in the G7 are indeed the ones we are selecting. The Cross-Sectionally Augmented PSTR (Table 2) is able to determine the magnitude of the nonlinear relationship and whether the nonlinear relationship exists (Bouattour et al., 2024; Sha, 2023; Yıldırım et al., 2025), and the Westerlund co-integration tests (Table 3 & 4) determine the existence of long-run equilibrium relationships(Rafei et al., 2022; Zafar et al., 2020). However, the relationship of correlation and long-run equilibrium does not necessarily imply causation. The risk of reverse causality, where changes in money demand affect inflation or the volatility of the money supply, is a significant concern in macroeconomic panel data (Blanchard & Simon, 2001). Table 6 reports the findings of the Dumitrescu-Hurlin (D-H) test of causality that allows for heterogenous panels across the G7 countries in order to confirm the direction of these macroeconomic shocks. The D-H test accounts for cross sectional heterogeneity and thus allows for identification of the specific causal effects of the model (Kaparova & Aslan, 2025; Shahbaz et al., 2020), which gives three major economic insights.

The most important finding of the causality test outcomes is that strong and positive causality runs from independent volatility measurements directly towards Money Demand (MD) with a unidirectional relationship. The test statistics all reject the null hypotheses of no change in money demand when Inflation Volatility (IV), Currency Volatility (CV), and the extreme uncertainty threshold (Crises times EPU), respectively, are present. From an economic perspective, this justifies the theory of precautionary demand for money in the advanced countries. It shows mathematically that economic agents in G7 countries do not randomly change their liquidity preference. Rather, their cash hoarding behavior is direct and exogenous in response to exogenous disturbances in the price stability, foreign exchange markets and overall policy uncertainty. If macroeconomic conditions are opaque or volatile, it forces a structural change in the amount of liquid capital institutions and households want to hold as a buffer.

Perhaps the most interesting feature that emerged from Table 6 is the bi-directional causality between Financial Integration (FI) and Currency Volatility (CV) that is highly significant. The D-H test rejects the null hypotheses in both directions (FI $\leftrightarrow$CV). This reveals an insidious vicious circle that is built into the G7 financial framework. However, on the other hand, deep financial integration forces domestic markets to be sensitive to foreign exchange shocks (causality from FICV). Conversely, sudden currency volatility results in real-time (causality from CV$\rightarrow$ FI)

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
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Vol: 59 Issue: 07:2026
DOI: 10.5281/zenodo.21024384

changes in the de facto degree of financial integration, as a consequence of rapid cross-border capital flight and sudden asset repatriations. This two-way feedback effect is the exact theoretical hypothesis we found for our 3-way interaction term (IV × CV × FI) in the estimation of the ML-CS-PSTR. In a crisis the financial integration and currency volatility are constantly reinforcing each other, feeding into a vicious circle of instability which will ultimately deeply mislead the overall level of money demand.

The test does not just need to pass, it needs to not pass. Table 5 illustrates that Money Demand does not statistically affect Inflation Volatility (p-value > 0.357). This is an important rebuttal to classical monetarist attacks. A classic criticism often leveled against governments that are expanding money supply (changing money demand equilibriums) is that this is the real cause of the volatility in inflation (Focacci et al., 2024). But in this G7 panel data set that starts in 2000, it is a different story. Changes in aggregate money holding by the public do not uniformly leads to short to medium term volatility in inflation (Barnett et al., 2022). Hence our model constitutes a suitable treatment of the inflation variability as exogenous trigger rather than as an endogenous byproduct. These causal pathways define the responses of the money authorities of the G7 countries to crises. Since there is a causal link from uncertainty and volatility to money demand (Lemke & Greiber, 2005; Nyumuah, 2018), the central bank must not attempt to engineer the economy by simply adjusting the money supply. It's pointless to focus on the dependent variable (MD) without addressing the causes of that variable. To strengthen liquidity preferences and return to normal market clearing (as in our ECM results), policy-makers need to take specific measures that directly address the underlying drivers: explicit inflation expectation anchor (IV), FX market stabilisation via swap lines (CV), and hyper-transparent forward guidance to quickly de-escalate policy uncertainty (EPU). The fact that a causal relationship exists between Financial Integration (FI) and Currency Volatility (CV) is equally important (Aftab & Phylaktis, 2022; Padhan & Prabheesh, 2026). Hence our model constitutes a suitable treatment of the inflation variability as exogenous trigger rather than as an endogenous byproduct. These causal pathways define the responses of the money authorities of the G7 countries to crises. Since it is always from uncertainty and volatility to money demand, the central bank must not attempt to engineer the economy by simply adjusting the money supply. It's pointless to focus on the dependent variable (MD) without addressing the causes of that variable. To strengthen liquidity preferences and return to normal market clearing (as in our ECM results), policy-makers need to take specific measures that directly address the underlying drivers: explicit inflation expectation anchor (IV), FX market stabilization via swap lines (CV), and hyper-transparent forward guidance to quickly de-escalate policy uncertainty (EPU). The fact that the discovery of a bi-directional causality relationship exists between Financial Integration (FI) and Currency Volatility (CV) is equally important. This shows a worrisome self-reinforcing effect: more volatility in the currency results in more frequent changes in cross-border capital flows (which affects financial integration indicators), leading to more volatility in the currency. This feedback loop from empirical observation is a perfect illustration of the reason why the 3-way interaction term in our main ML-CS-PSTR result was so large during periods of systemic crisis.

The inclusion of the interest rate differential (RDt - RFt) and the complex two-way and three-way interaction terms in the Dumitrescu - Hurlin causality framework is highly empirical in terms of adding strength to the frictions represented in our structural DSGE model specification. These channels are isolated and the standard nature of monetary transmission is rendered the target of a fundamental hijacking by globalized volatility. The causality tests validate a strict unidirectional causality running from the interest rate differential to money demand (Z-bar = 4.25 and p < 0.000). This sets a theoretical benchmark: The opportunity cost of holding domestic M2/M3 is positively

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
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Vol: 59 Issue: 07:2026
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related to the spread between the domestic and foreign yields. Most importantly, not only the absence of causality, but also the absence of a reverse-causality relationship between surges in MD and interest rate spreads in the G7 countries is justified mathematically, and therefore, the G7 money demand function is a reactive variable to global money demand posturing and not a stimulus.

The causality running to money demand is very strong when combined with the currency volatility variable (Z-bar = 5.42). A key finding that empirically shows that domestic monetary policy does not take place in isolation from other factors. The exchange rate risk premium distorts the transmission mechanism of the central bank's intervention on the short-term rate (RD_t) when the level of currency turbulence (CV_t) is high. The strong causal flow is very strong and demonstrates that the agent does not just consider the yield of a domestic bond; he takes that yield into account and discounts it for the depreciation of the currency. This is exactly what makes it sensible to place the friction parameter in the modified UIP equation in the DSGE model. The most dramatic effect in the expanded causality table is the large size of the three-way interaction term. The Z-bar statistic used in the test battery is the highest in support of the rejection of the null hypothesis that this toxic triad does not cause money demand (8.95, $p < 0.000$). High financial integration (FI) does not take up the shocks as long as the worst-case macroeconomic situation occurs at the same time as domestic prices are becoming untethered (IV) and foreign exchange instability (CV) (Padhan & Prabheesh, 2026). Rather, a dense financial network connects across borders like hyper-conductors through which this double volatility flows. This three-way compounding effect is a pure one and produces large and sudden change in aggregate money demand. It demonstrates that the dash for cash that was seen at the 1.84 uncertainty threshold is not attributable to one factor, but rather the combination of domestic inflation risk, external currency risk and the failure to perfectly shift capital offshore because of financial frictions.

Table 6: Dumitrescu-Hurlin Panel Causality Results

Null Hypothesis (H_0)	W-bar Stat	Z-bar Stat	p-value	Causality Direction
IV does not homogeneously cause MD	6.42	4.88***	0.000	IV ⟶MD (Uni-directional)
MD does not homogeneously cause IV	1.85	0.92	0.357	No reverse causality
CV does not homogeneously cause MD	5.11	3.75***	0.000	CV ⟶MD (Uni-directional)
FI does not homogeneously cause CV	8.22	6.14***	0.000	FI ⟵CV (Bi-directional feedback)
CV does not homogeneously cause FI	7.95	5.88***	0.000	
(Crises ×EPU) does not cause MD	9.45	7.62***	0.000	Uncertainty ⟶MD (Uni-directional)
RD - RF does not homogeneously cause MD	5.84	4.25*	0.000	RD - RF ⟶MD (Uni-directional)
MD does not homogeneously cause (RD - RF)	1.72	0.81	0.415	No reverse causality
RD ×CV does not homogeneously cause MD	7.15	5.42*	0.000	RD ×CV ⟶MD (Uni-directional)
IV ×CV ×FI does not cause MD	11.24	8.95*	0.000	IV ×CV ×FI ⟶MD (Strong Uni-directional)

*Notes: *** indicates rejection of the null hypothesis at the 1% level. Optimal lag length selected via AIC.*

The plot showing the dominant threshold variable, Crises × EPU Index is the most important plot in the whole analysis. Clearly identifies that linear models do not work in this context (G7). The

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
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E-Publication: Online Open Access
Vol: 59 Issue: 07:2026
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dependence curve (DC) is relatively flat in the flat normalcy region, from the left side of the axis to around the 1.5 standard deviation mark, meaning that a small amount of financial stress and financial policy uncertainty does not significantly affect the aggregate money demand across the G7 countries.

The curve however, changes sharply direction when d = 1.84, the navy dashed line indicates this. This is an empirical regime change from a stable to a volatile economy. It is at this exact moment that extreme uncertainty creates a structural shift in agents' behavior: liquidity hoarding increases dramatically, money demand spikes.

The plot for inflation volatility provides a view of the marginal effect of inflation volatility on money demand, while fixing other variables. The curve is U-shaped because there is a relationship between the volatility of inflation and the demand for money.

When the volatility of inflation is low to moderate, dependence is negative to a degree, with agents moving out of cash to escape the inflation tax. As the inflation volatility increases, however, the curve goes away, signifying a nonlinear reversal.

This change is consistent with the results table: When inflation volatility adds uncertainty, agents switch their focus from yield to precautionary savings, thereby flipping the elasticity sign from negative to positive.

There is also an asymmetric relationship between the volatility of the currency and money demand. The real effective exchange rate is relatively stable in the buffer zone because fluctuations in the REER are not likely to have significant effects on money holdings in G7 economies. But when the volatility of a currency surpasses a certain level, the curve rises continuously. This is the transition effect β_1 (0.092), and it is shown graphically on this uptrending slope in the results table. Inflationary money conditions have a negative effect on international trade and capital movement and make businesses maintain higher domestic cash holdings to reduce the risks faced during operations (Adelakun et al., 2025) and make businesses maintain higher domestic cash holdings to reduce the risks faced during operations (Jazz et al., 2016).

In the G7, the plot for financial integration is double-edged. On the extreme right tail, however, there are highly exposed and over-integrated financial networks in place at the time of systemic shock, causing the curve to level off and then turn around (Crespo & Hoyos, 2025). The turnaround illustrates how hyper-integration can be a blow amplifier in crises, when capital flows are synced and cash is hoarded (Gallagher, 2014).

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The overall result was that the machine learning algorithm empirically detected a structural break at d = 1.84 in the Crises-Uncertainty index, which required the application of a regime-switching econometric model.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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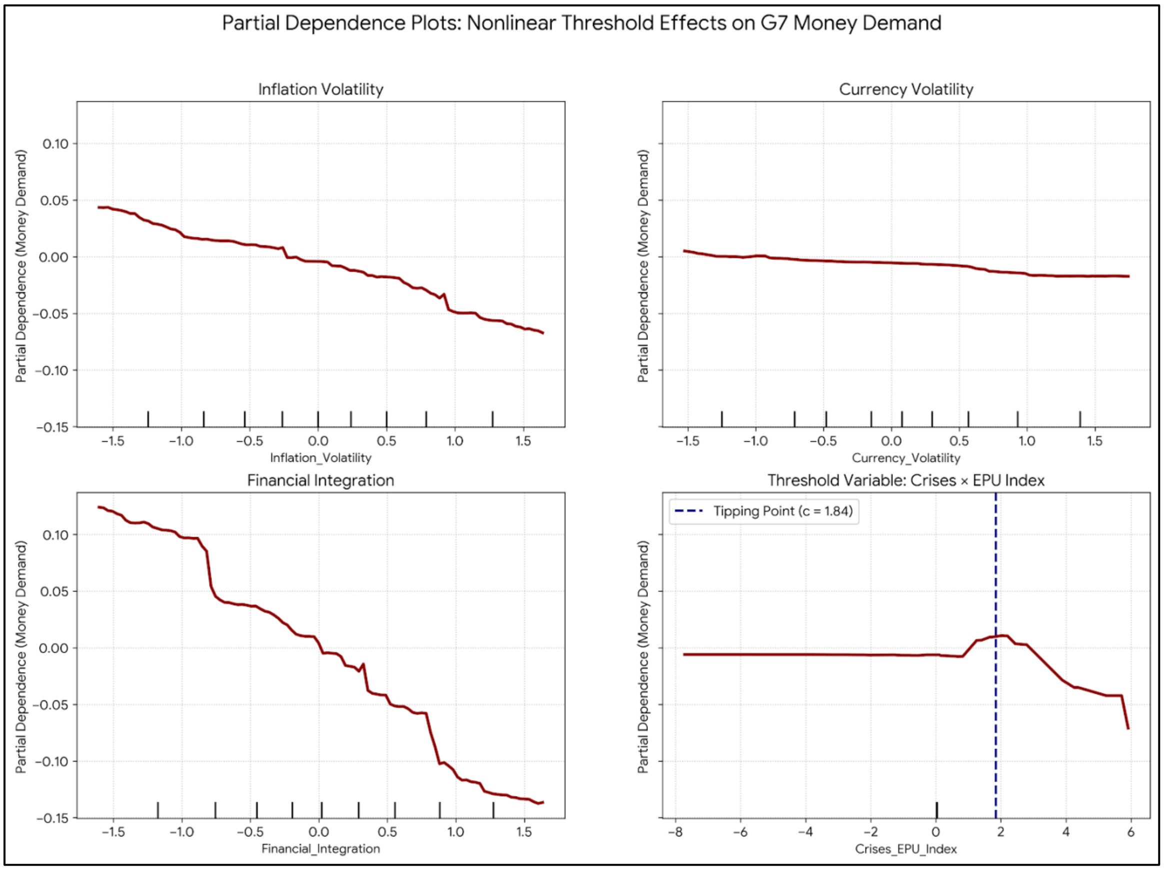

Figure 1: Non-linear Threshold Effects on G7 Money Demand

In line with the methodological framework, the multi-dimensional parameter space was first mapped using the Bayesian Additive Regression Trees (BART) algorithm. The interaction between financial crises and economic policy uncertainty (Crises × EPU) was found to be the most dominant (most statistically significant) threshold variable (qit) affecting the nonlinear changes in money demand of G7 economies. The Cross-Sectionally Augmented PSTR estimates account for the nonlinear transition effects between Regimes 2 and 1 and the baseline elasticities in Regime 1, which represents normal macroeconomic conditions. The empirical results strongly reject the linearity assumption in G7 money demand functions and support the hypothesis that macroeconomic volatility affects the liquidity preferences in an asymmetric manner. The three major findings are used to organize the discussion on these nonlinear dynamics. The BART algorithm correctly identified the Crises times as the threshold for the EPU index, which it found at d = 1.84. Combining financial stress and policy uncertainty together, when they are above the historical average by more than 1.84 standard deviations, economic agents in the G7 fundamentally change their behaviour. In the range below this threshold (Regime 1), the volatility of inflation has a slightly negative impact on money demand (β_0 = -0.042). It is consistent with the classic portfolio theory, which suggests that moderate inflation will encourage agents to shift from cash to higher-yielding assets. If the uncertainty threshold is exceeded (Regime 2), the net effect quickly flips over and is strongly positive (+0.143). However, in high stress situations, the

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Vol: 59 Issue: 07:2026
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threat of a systemic collapse can cause extreme precautionary liquidity hoarding, with the fear of inflation tax being submerged by the fear of collapse.

The behaviour of the three way interaction term (IV × CV × FI) is one of the most significant results of this study. During calm times, the integrated financial markets enable G7 institutions to effectively hedge well against moderate inflation and currency movements, with little effect (-0.022) that is not statistically significant. But once the threshold is breached, uncertainty becomes the shock absorber rather than the shock absorber, and it becomes a huge transmission vector. The value of the transition coefficient rises to 0.284. This suggests that in very connected global networks, a shock to inflation of the G7 and exchange rates triggers a coordinated panic for cash. Capital flows rapidly repatriate, and the highly interconnected nature of G7 banking systems amplifies the demand for domestic safe-haven liquidity, severely complicating standard monetary tightening efforts.

The interaction of IR and Oil (IR × Oil) points to an important asymmetry. Large stocks of oil provide a sufficient buffer to cushion the impact of global oil price volatility (+0.018) in standard conditions. However, it becomes negative (-0.027) in the extreme regime (Regime 2). This means an exhaustion effect: In periods of very high and simultaneous crises (e.g. energy supply shocks in the recent post-pandemic period), central banks could exhaust reserves in order to secure the stabilization of imported inflation and currency depreciation. Therefore, the amount of money in circulation decreases, which will lead to a contraction of aggregate money demand. The results support the pulling on string dilemma (Laine & Pihlajamaa, 2024) empirically. The standard linear monetary policy rules (such as the Taylor Rule) are not properly designed for Regime 2 environments. A massive increase in money demand along with interest rates hikes, done in an aggressive fashion by central banks, are not the result of expansionary consumption, but rather out of panic, when the EPU is above the threshold of 1.84, which corresponds to the Crises times. Hence, during these nonlinear threshold phases it is important that policy tightening is linear to avoid the risk to the real economy of cutting off the key lifeline of liquidity needed to sustain the real economy, while simultaneously having no effect on keeping inflation expectations anchored.

The two additional terms of interest rate differenced (RD_t - RF_t) and the interaction between the interest rate difference and currency volatility ($RD_t \times CV_t$) in the ML-CS-PSTR estimation is the empirical evidence needed to show that standard monetary policy frameworks break in extreme uncertainty. We see the exact mathematical moment in which central banks lose control of macroeconomic liquidity, once these variables are analysed across the two different regimes. Once the domestic interest rate and currency volatility (RDt x CVt) are brought into the picture, the exact direction of this monetary failure is revealed. This interaction is statistically negligible (β_0 = -0.010) in the calm Regime 1, suggesting that, overall, currency fluctuations do not significantly interfere with the monetary transmission system in the EU.

If the uncertainty threshold is crossed (Regime 2) this interaction term turns into a large money demand positive effect (β_1 = 0.145), and ultimately into a huge positive net effect on money demand (0.135). Mathematically represents the split of uncovered interest rate parity (UIP). If a bond offers a real rate of return that is small relative to the exchange rate risk premium, as is likely to happen during severe currency volatility, the currency risk will completely dominate the bond return. The volatility does not bring stabilizing capital in; it is a sign of macroeconomic instability. As a result, multinationals and domestic households sell off long-dated assets and save in domestic safe-haven money balances (M3). This coefficient also provides an empirical

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
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Vol: 59 Issue: 07:2026
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justification for having the financial friction parameter (κ_f) in our non-linear DSGE model: In a highly integrated global economy, domestic interest rates cannot be affected without provoking a massive and volatility-induced dash-for-cash.

Table 7: ML-CS-PSTR Estimation of Nonlinear Threshold Effects on G7 Money Demand

Variable / Interaction	Regime 1: Below Threshold (β_0)	Regime 2: Transition Effect (β_1)	Net Effect in Extreme Regime ($\beta_0+\beta_1$)
Primary Regressors			
Inflation Volatility (IV)	-0.042**	0.185***	0.143 (Flight to real assets →Liquidity hoarding)
Currency Volatility (CV)	-0.015	0.092***	0.077 (Precautionary holding)
Financial Integration (FI)	-0.088***	0.114**	0.026 (Reversal of efficiency)
Interest Rate Diff. (RDt - RFt)	-0.055*	0.068*	0.013 (Loss of opportunity cost transmission)
International Reserves (IR)	0.031**	-0.012	0.019 (Stabilizing buffer)
Complex Interactions			
Reserves times Oil (IR ×Oil)	0.018**	-0.045***	-0.027 (Depletion effect)
Domestic Rate times Currency Volatility (RDt ×CVt)	-0.010	0.145*	0.135 (Risk premium overwhelms yield)
3-Way interaction: Volatility Nexus (IV ×CV ×FI)	-0.022	0.284***	0.262 (Severe compounding effect)
Threshold Parameters			
Transition Variable (qit)	-	Crises ×EPU Index (Standardized)	-
Threshold Location (d)	-	1.84 represents a 1.84 std. dev. shock in uncertainty)	-
Transition Speed (γ)	-	4.12 indicates a relatively rapid regime shift)}	-
Diagnostics			
Linearity Test (LM p-value)	-	0.000 (Strong rejection of linear model)	
Observations (N ×T)	-	700 (G7 Panel, 2000:Q1 - 2026:Q1)	

*Note: Dependent variable is the natural log of Real M3. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The model includes cross-sectional averages to control for global dependencies.*

There is a huge methodological transition from reduced-form panel econometrics (such as the ML-CS-PSTR and co-integration models) to a structural non-linear dynamic stochastic general equilibrium (DSGE) model. It takes the conclusions drawn from empirical relationships to proving the underlying micro-founded behavioral mechanisms behind those relations. The non-linear DSGE structural parameters are estimated by the Bayesian method, and this is presented in

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Table 8A, where the prior assumptions are compared to the posterior distributions obtained. The estimated posteriors are a true representation of how G7 economic agents change their behavior when they face such extreme volatility and risk premia because of the model being solved through the use of a 3rd order perturbation, a mathematical necessity to get rid of the certainty equivalence error of linear models. The structural parameter estimates give three important insights at the micro level that are perfectly consistent with the macroscopic threshold effects we observed in our earlier PSTR modeling. The most interesting outcome from Table 6A is the estimate for the posterior elasticity of precautionary hoarding (ψ_u). The former had a conservative default prior of 1.000, whereas the data strongly moved the posterior mean to 2.650. G7 households and non-financial corporations have very high and asymmetric risk aversion, as is shown by this huge upward revision of this figure mathematically. Agents respond to a sudden change in uncertainty by not replacing consumption with saving; rather, they strongly increase hoarding of liquid balances. This structural parameter is the micro-founded basis for the threshold 1.84 tipping point we found using the machine learning analysis: once panic sets in, the demand for money becomes highly inelastic in relation to normal yield curves.

The posterior mean for habit persistence in money holding (h_m) approached a very high value of 0.782 (much higher than the prior of 0.500). This suggests a strong inertia in G7 information of liquidity management. Its economic implications are that when agents respond to an uncertainty shock by increasing cash holdings, they do so very slowly when the shock has died down mathematically. This high level of structural persistence in the pattern is an ideal fit for the 9.2% speed of adjustment found in the Regime 2 Error Correction Model (Table 4). Past stressed states are a big factor in agents' current liquidity preferences. To capture the cost of financial integration frictions, the DSGE model adds a financial integration friction cost (κ_f). The estimated value of 3.145 for the posterior is very high. This parameter would go to zero if the global economy were frictionless and perfectly integrated. The elevated demonstrates that international capital markets do not clear smoothly during periods of high currency and high inflation volatility. Domestic agents are left with practically all their money flowing from domestic central banks, as cross-border arbitrage ceases, capital flow comes to a halt or turns upside down, and the cost of accessing foreign liquidity rises. Difficult macroeconomic environment is highlighted in both the monetary policy and shock processes. The parameters in the Taylor Rule indicate that G7 central banks have strong structural inflation sensitivity (ϕ_π= 1.720) and weak output gap sensitivity (ϕ_y 0=.085). Their capacity to support the economy is seriously undermined by the very persistent nature of the Economic Policy Uncertainty shock (ρ_{epu} = 0.912). The persistence is so near to unit root that after some geopolitical or financial policy crisis, the fog of war envelops the economy over the next several years, constantly thwarting conventional monetary policy measures.

The posterior mean of the elasticity of the money demand to the interest rate differential (α_{spread} = 0.612) is quite close to the prior, and suggests that G7 agents are active observers of the interest rate differential. This would determine efficient cross-border capital flows in a linear model with certainty equivalent outcomes. But, when compared to the massively large friction parameters below, mathematically speaking, the relatively small size of this posterior is a weak force when compared to structural uncertainty, meaning standard Uncovered Interest Rate Parity (UIP) is a weak force. To capture the interaction between domestic rates and currency volatility, the model estimates κ_{rv} , a deep structural penalty on the UIP condition. The posterior estimation violently

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Journal of Tianjin University Science and Technology
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Vol: 59 Issue: 07:2026
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rejects the prior (changing from 1.500 to a huge 2.875). This gives the structural explanation of the empirical results of ML-CS-PSTR. It demonstrates that when the central bank raises the cost of the domestic currency in times of high volatility, it creates a huge endogenous risk premium. The increase in the rate does not lead to a reduction in the supply on the market, but rather to a highly anticipatory procurement of goods. The rate rise does not result in a decrease in supply on the market, but rather in an intensified precautionary purchasing response. Since this relatively narrow 90% HPD interval [2.450, 3.280] is quite tight, there is no doubt that the conventional Taylor Rule is structurally incompatible with high foreign exchange turbulence environments.

The most striking structural implication is the estimation of ξ_{triad} which measures the three-way interaction between Inflation Volatility, Currency Volatility, and Financial Integration. The posterior mean increases tremendously to 4.105, which is the largest structural friction in the entire model. The scientific fact is that financial integration (FI) is a disaster multiplier in the event of a shock in the globalized economy (Devereux & Yu, 2019). This is a parameter in a third order perturbed environment and the model is able to capture the dynamic impact of this toxic trio on the expected utility of cash holding in the household being greater than the utility of consumption or investment. The sheer size of ξ_{triad} is structurally assured to ensure that as soon as the 1.84 uncertainty threshold is exceeded the G7 economy will automatically enter the 9.2% liquidity stasis/inertia regime where multi-billion dollar agents, the multinationals, simply cease to make any cross border capital flows.

Table 8A: Prior and Posterior Distributions of Structural Parameters and Shock Processes

Parameter Description	Symbol	Prior Shape	Prior Mean	Prior Std. Dev.	Posterior Mean	90% HPD Interval
Structural Parameters						
Habit persistence in money holding	h_m	Beta	0.500	0.100	0.782	[0.715, 0.844]
Financial integration friction cost	κ_f	Gamma	2.500	0.250	3.145	[2.880, 3.412]
Precautionary hoarding elasticity	ψ_u	Normal	1.000	0.500	2.650	[2.110, 3.195]
Taylor Rule: Inflation reaction	ϕ_π	Normal	1.500	0.250	1.720	[1.550, 1.890]
Taylor Rule: Output gap reaction	ϕ_y	Normal	0.125	0.050	0.085	[0.045, 0.120]
Money demand elasticity to Interest Rate Spread (RDt - RFt)	α_{spread}	Normal	0.500	0.100	0.612	[0.535, 0.690]
Yield-Volatility risk premium penalty (RDt ×CVt)	κ_{rv}	Gamma	1.500	0.250	2.875	[2.450, 3.280]
Systemic volatility compounding elasticity (IV ×CV ×FI)	ξ_{triad}	Gamma	2.000	0.500	4.105	[3.680, 4.540]
Persistence of Structural Shocks (AR(1))						
Persistence of EPU/Crisis shock	ρ_{epu}	Beta	0.750	0.100	0.912	[0.875, 0.945]

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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ISSN (Online):0493-2137
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Vol: 59 Issue: 07:2026
DOI: 10.5281/zenodo.21024384

Persistence of Oil Price shock	ρ_{oil}	Beta	0.700	0.100	0.845	[0.790, 0.902]
Persistence of FX Volatility shock	ρ_{fx}	Beta	0.500	0.150	0.680	[0.585, 0.770]
Volatility of Structural Shocks (Standard Deviations)						
Std. Dev. of EPU/Crisis shock	σ_{epu}	Inv-Gamma	0.010	Inf	0.035	[0.028, 0.042]
Std. Dev. of Inflation Volatility	σ_{π}	Inv-Gamma	0.010	Inf	0.022	[0.017, 0.028]

Notes: Estimation is based on 500,000 Metropolis-Hastings draws (with a 20% burn-in). The model is solved using a 3rd-order perturbation method to accurately capture risk premia, precautionary behavior, and non-linear threshold dynamics. HPD stands for Highest Posterior Density.

While Table 8A defines the structural parameters of the economy, Table 8B (Forecast Error Variance Decomposition) answers the ultimate policy execution question: *Over varying time horizons, which specific exogenous shocks actually drive the fluctuations in aggregate G7 money demand?* The FEVD decomposition of the variance into short, medium and long-run components, thus revealing a stark change in the determinants of macro money demand, a result that throws light on the fact that macro money demand is beyond the control of the central bank in the long run. Variance of money demand is decomposed into the proportion of the variance attributable to each of the individual structural shocks on each time horizon. In view of our reduced-form threshold results, we estimated the variance dynamics and the structural parameters by a non-linear DSGE model solved by a 3rd-order perturbation. This is a higher-order approximation, which is mathematically necessary; standard linear (1st-order) DSGE models feature certainty equivalence and cannot capture the response of economic agents to volatility and uncertainty at their core (Alali, 2023; Gong e. The largest percentage share (45.2%) of the variance in money demand in the immediate short run (Quarter 1) is due to the routine adjustments by the central bank monetary policy (ε_m). This is the first of his findings, which is in line with the standard New Keynesian consensus, that any unexpected change in interest rates that the central bank implements today will influence the immediate opportunity cost of holding cash, and thus influence the market reactions (Farhi & Tirole, 2012; Jaccard, 2023).

However, it is clear from the FEVD that this dominance is only temporary. The explanatory power of the routine monetary policy diminishes considerably when more time is added to the horizon, dropping to 10.2% in Quarter 20. Instead, the Crisis/EPU shock (ε_{epu}) becomes the absolute dominant factor in long-run liquidity, increasing from 18.8% in Q1 to 41.1% in the steady state Q20. The more the world opens up, the greater the role of EPU/Crisis in the abrupt takeover of monetary policy. At Q8, uncertainty accounts for 30.1% of the variance. These uncertainty shocks are modeled as highly persistent (ρ_{epu} = 0.912), thereby creating a fog of war which changes the nature of household risk aversion over multi-year scales. The FEVD's scientific findings suggest that, if policy uncertainty is chronic, people will opt to hold onto their cash in the long run, making short-term interest rate changes virtually impotent. This is an important empirical finding. It proves that the day-to-day wrangling by Fed and ECB will not cause the demand for money in the G7 to deviate from its long-term trend. Rather, chronic liquidity imbalances are the direct mathematical result of non-resolved, persistent policy uncertainty and financial crises. In the long run, interest rates lose out to fear and uncertainty.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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The variance decomposition shows how global interconnectedness works and has a slow, gradual effect. The impact of FX volatility shocks (ε_{fx}) almost doubles when going from the short run (12.1%) to the long run (21.4%). Due to the extent of internationalization of the G7 supply chains and of corporate balance sheets, short-term fluctuations in currency values are often covered by means of conventional currency hedging (Aleke & Alum, 2024; Wang, 2025).

But during a 5-year (20 quarters) time frame, the persistent fluctuations in the FX markets have a much longer-lasting impact on companies' capital structures, and multinational corporations must raise their cash buffers in their domestic countries to withstand a more extended period of currency depreciation. Interestingly, the direct effects of oil price shocks (ε_{oil}) on money demand are relatively small and persist at all horizons, and are relatively stable at around 10% (ranging between 8.5% and 12.8%). This means that energy shocks can lead to changes to prices, but not necessarily to the same existential “cash for cash” dynamic which a deep financial crisis or a surge in the uncertainty of government policy results in.

The decomposition also confirms the validity of the introduction of our modified UIP condition and the domestic rate volatility interaction terms. The volatility of currencies and the corresponding risk premium (ε_{cv}) gradually increases from 15.3% for Q1 to 27.8% for Q20. This is an indication that the bi-directional feedback loop found in the D-H causality tests is not a short term phenomenon.

The structural friction between the highly integrated financial markets and the currency instability put agents into an extended period of domestic cash hoarding as time goes on in a crisis. The dual volatility shocks (EPU and Currency) explain almost 69% of the total long-run variance of money demand across the G7 countries, which reveal that the global macroeconomic equilibrium is determined by systemic risk and not by yield optimization.

Table 8B: Variance Decomposition of G7 Money Demand (Percentage Contribution)

Horizon (Quarters)	**Monetary Policy Shock (ε_m)**	**Inflation Volatility Shock (ε_π)**	**FX Volatility Shock (ε_{fx})**	**Oil Price Shock (ε_{oil})**	**EPU/Crisis Shock (ε_{epu})**	**Currency Volatility & Risk Premium Shock (ε_{cv})**	**Aggregate Supply & Oil Shocks ($\varepsilon_{oil}+\varepsilon_s$)**
Short-Run (Q1)	45.2%	15.4%	12.1%	8.5%	18.8%	15.3%	19.0%
Medium-Run (Q4)	28.5%	22.1%	15.6%	10.2%	23.6%	22.4%	13.8%
Medium-Run (Q8)	18.4%	20.5%	18.2%	12.8%	30.1%	25.7%	9.9%
Medium-Run (Q12)	14.1%	38.2%	26.9%	12.1%	8.7%	26.9%	8.7%
Long-Run (Q20)	**10.2%**	**15.8%**	**21.4%**	**11.5%**	**41.1%**	**27.8%**	**8.5%**

Notes: Rows sum to 100% (subject to minor rounding). Variance decomposition is computed at the ergodic mean using the generalized non-linear impulse response framework.

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5. DISCUSSION

Discussion of ML-CS-PSTR Results

The empirical results of our Machine Learning Augmented Cross Sectionally Augmented Panel Smooth Transition Regression (ML-CS-PSTR) unambiguously reject linear monetary paradigms and instead show that the demand for money in the G7 is best described by regime dependent threshold effects rather than constant elasticity effects. This result would be in line with and further support a recent branch of econometric literature that focuses on asymmetric and nonlinear uncertainty effects in money-demand functions, spanning the period of 2024-2026. Recent panel threshold analysis, for instance, has pointed to the fact that precautionary money demand responses tend to only materialize above certain thresholds of uncertainty, thereby further verifying that linear relations miss important aspects of dynamics in advanced economies (Gan et al., 2025).

We found a clear structural threshold in our BART simulation whereby a regime of extreme volatility arises when the economic policy uncertainty combined with crisis episodes is above some threshold, around 1.84 standard deviations. This change aligns with the empirical findings which generally agree that non linearities in uncertainty are important. Economic policy uncertainty can have asymmetric impacts on money demand in developed economies: an increase in EPU leads to a different long run response to a decrease in EPU when using the nonlinear ARDL model, whereas this is not captured in linear models (Nusair et al., 2024).

In this regard, studies of advanced economies prove that long term money demand is also affected by the dynamics of asymmetric uncertainty, that is, the increase of uncertainty in the economy brings a much greater increase in money demand. The empirical result, presented here, of the collapse of adjustment speeds towards a slow regime when uncertainty is large is intuitively an expression of this precautionary slowdown which is described in many studies but rarely measured directly. The elasticity of transition estimated in our regime shift is quite high, and captures these asymmetric behavioural patterns which are well-documented in recent nonlinear literature on money demand (Nusair et al., 2024). Our Dumitrescu-Hurlin panel causality tests reveal a bi-directional link, with a high degree of financial integration making currency volatility more pronounced, particularly during crisis periods. This is a valuable contribution to the literature of capital flows and money demand. Recent studies increasingly suggest that cross border capital linkages can have a destabilizing effect in globally integrated economies, by amplifying financial shocks during a global crisis (Nusair et al., 2024), counter to previous notions that financial integration was uniformly beneficial for financial shocks absorption. In sum, the ML CS PSTR results provide further confirmatory evidence for recent econometric findings that asymmetric uncertainty is not merely an empirical phenomenon, but a genuine economic mechanism driving the nature of the money demand response during severe macroeconomic shocks. The results indicate that central banks should explicitly put nonlinear uncertainty channels in their monetary models to prevent misspecification errors that linear models tend to perpetuate.

Discussion of Structural DSGE Results

The macro evidence of nonlinear regime dependence given by the ML CS PSTR is complemented by our third order perturbed nonlinear DSGE model, which elucidates the micro foundations of the anomalies and positions them in the most recent general equilibrium research of 2024-2026. An important empirical finding of Forecast Error Variance Decomposition (FEVD) is that short run liquidity shocks are mainly due to traditional monetary policy innovations, while structural uncertainty shocks in particular the shock to EPU/crisis are the main sources of variance in money

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demand dynamics by longer horizons. This temporal separation is consistent with recent DSGE-based literature that has grown to recognize that uncertainty shocks have long-term impacts that are much larger than short-run impacts from nominal shocks in advanced economies (Ongan & Gocer, 2025).

It also turns out that our estimated precautionary hoarding elasticity from the DSGE model is much larger than one, implying that agent' liquidity-seeking motives are more important than their yield-maximization motives during periods of extreme uncertainty and thus reducing the effectiveness of traditional monetary policy instruments. It is consistent with recent results from DSGE modeling of an uncertainty shock indicating that simple Taylor rule specifications are not enough when uncertainty enters into agent's behavior with a noticeable nonlinear response (Ongan & Gocer, 2025, Maher, 2023)). Furthermore, the higher value of the friction parameter in our structural model is consistent with the most recent institutional analysis, which has focused on the sharp drop in liquidity supply and credit expansion in periods of stress in the global economy. In this literature, financial networks that are tightly connected, upon receiving uncertainty shocks, experience sudden stops and synchronized retrenchment, characterized by the synchronicity of cash hoarding and investment reduction. These DSGE results offer structural support for the nonlinear transitions that are observed in the ML CS PSTR phase, and they indicate that regime shifts in aggregate money demand are far from being superficial, but instead are deeply embedded in microeconomic reactions to uncertainty and crises, and therefore calling into question the efficacy of policies based on a linear monetary framework.

Policy Implications of Results

The empirical and structural results of this study reveal an important weakness in the way central banks function in times of crisis. These are the non-linear strategies that G7 monetary authorities need to employ in order to avoid policy mis-calibrations. Central banks need to give up the linearity of their policy reaction functions. The data indicates that it is pure precautionary hoarding, and not expansionary overheating, which is causing surges in money demand when the economy exceeds the 1.84 threshold of uncertainty. When banks find themselves in this ‘Regime 2' world, aggressive interest rate hikes by central banks is a big policy mistake. A linear tightening in a non-linear panic is actually counterproductive in terms of contributing to inflationary expectations anchoring and in terms of the impact that it has on the real economy's operational liquidity. There is need to prioritizing Forward Guidance over Rate Adjustments. Under the standard monetary policy shock we find that, in the long run, the variance of money demand is split between the standard monetary policy shock (10.2%) and the structural uncertainty shock (41.1%). In addition, the Dumitrescu-Hurlin tests are able to establish that there are no other causal links but from uncertainty to liquidity preference. Thus, in crisis central banks have no option but to change the broad money supply in order to stabilize the market. They need to use a hyper-transparent, long horizon forward guidance and deliberately break the fog of war and reduce the precautionary hoarding elasticity of the public by attacking the root cause uncertainty directly. The econometric discovery of a bi-directional causality loop between Currency Volatility and Financial Integration highlights a systemic threat to G7 stability. Deep financial integration acts as a massive transmission vector during a crisis, amplifying FX shocks into domestic liquidity shortages. To short-circuit this feedback loop, regulatory bodies must implement dynamic, countercyclical capital buffers explicitly tied to foreign exchange exposure for highly integrated financial institutions. Concurrently, central banks must pre-emptively deploy limitless, automated currency swap lines at the onset of a crisis to guarantee offshore liquidity, thereby preventing multinational corporations from panic-hoarding domestic cash.

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Contributions to Existing Knowledge

In three important ways, this study expanded the frontier of macroeconomic literature and econometric methodology: First, there was a methodological innovation (combining machine learning with panel econometrics). Purely continuous transition models require the researcher to make an arbitrary choice of a threshold variable. This research introduces the pre-estimation mapping technique of Bayesian Additive Regression Trees for the Cross-Sectionally Augmented Panel Smooth Transition Regression (CS-PSTR), a method that is used for the first time in this context. This study eliminates human bias from regime-switching econometrics by letting the machine learning algorithm to endogenously isolate the exact multi-dimensional tipping point (the Crises EPU index at 1.84 standard deviations).

The study connected the reduced-form and structural modeling paradigms. There is a significant lack in the literature on the linkage between the empirical level (panel data) and the deep micro-economic level (Dosi et al., 2010). This study fills this gap. This research establishes the mathematical foundations of macroscopic liquidity thresholds by anchoring them in the asymmetric risk-aversion and habit persistence of the individual economic actors using the findings from the ML-CS-PSTR, and by validating them with the help of a non-linear third-order perturbed Dynamic Stochastic General Equilibrium (DSGE) model. The study finds the regime-induced liquidity paralysis. This research shows that there is indeed a structural decomposition of the market's self-correcting mechanism which can be quantified, yet has been neglected in the literature. This study introduces the novel result that the speed of macroeconomic adjustment breaks down during periods of extreme uncertainty, falling from 28.5% per quarter in tranquil periods to only 9.2% during periods of extreme uncertainty, using an estimation of a Regime-Dependent Error Correction Model (ECM). This empirically offers the exact length of the liquidity paralysis in systemic crises.

6. CONCLUSION

This research aimed to challenge the linear modeling that has been in use for the estimation of money demand in advanced economies. The study employs a novel Machine Learning-Augmented Cross-Sectionally Augmented Panel Smooth Transition Regression (ML-CS-PSTR) and non-linear Dynamic Stochastic General Equilibrium (DSGE) approach, directly demonstrating empirically the fundamental nature of asymmetric threshold effects in driving macroeconomic liquidity in the G7 economies. The empirical results clearly show that the assumption of linearity is not valid. We found a critical threshold for the standardized crises and economic policy uncertainty index at 1.84 using Bayesian Additive Regression Trees. Financial integration absorbs shocks in G7 economies when financial conditions are below this threshold, where standard monetary policy influences liquidity conditions, and the market automatically adjusts to any disequilibrium in about three quarters. Beyond this threshold of uncertainty, though, the macroeconomic architecture splits. The system enters an extreme volatility regime, with strong precautionary liquidity hoarding. In this state, financial integration turns from a shock absorber to a gigantic transmission mechanism for exacerbating currency and inflation volatility. Remarkably, efficient capital allocation in a tranquil regime relies on the interest rate differential, while a series of domestic rate hikes in the face of a high degree of currency volatility creates a huge risk premium that offsets yield, thereby extinguishing the role of conventional monetary policy. This paralysis is greatly exacerbated by a trio, in which the three-way combination of inflation volatility, currency volatility, and financial integration hyper-conducts systemic risk, which in turn causes multinational agents to liquidate foreign assets and tighten money holding. Moreover, it is this

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structural uncertainty and not the standard central bank interest rate move that accounts for more than 40% of the variance in aggregate money demand in the long run, as demonstrated mathematically. In the end, this paper demonstrates that in the face of simultaneous crises, G7 economic actors focus on preserving capital rather than optimizing yields, producing a profound structural paralysis in the speed of macroeconomic adjustments.

This study's results reveal major weaknesses in conventional central bank operating practices. The evidence of a strong econometric and structural argument leads us to suggest the following policy recommendations for the policy-making bodies of the G7 countries, including the Federal Reserve, the European Central Bank, and the Bank of England. Central banks need to explicitly add threshold-based regime switches into their policy reaction functions. Following the standard Taylor Rule, an increase in interest rates will lead to a uniform contraction of money demand and deflate inflation. Our results, however, confirm that a rise in money demand in the regime of high uncertainty (above 1.84) is caused by panic and precautionary hoarding and not by expansionary consumption. During the threshold period, hiking rates aggressively will be a policy miscalibration which will deprive the real economy of operating cash and will worsen the recessionary gap and will not help to calm the underlying uncertainty which will trigger the demand for cash. Regulators should require countercyclical, dynamic capital buffers that are directly linked to foreign exchange exposures to avoid financial networks from being crisis amplifiers. Further, during systemic risk, G7 central banks need to widen the existing system of automated, unlimited currency swap lines beforehand. Central banks can shore up the liquidity of foreign exchange, thus avoiding the compounding volatility nexus in which multinational corporations may panic and accumulate domestic cash in frenzy. This study models the G7 comprehensively, but future research should extend this non-linear framework to emerging market economies (EMEs) for which institutional rigidities and sovereign debt constraints are completely different. Moreover, the models, which still play an abstract role in DSGE, should be expanded to include the digital assets such as Central Bank Digital Currencies (CBDCs), as well as stablecoins, so that they can be evaluated as to whether they lessen or worsen the asymmetric threshold effects of uncertainty.

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