MONETARY POLICY AND THE PANDEMIC: A SVAR Analysis of Monetary Policy in the COVID-19 Era

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Abstract

This work studies the effectiveness of monetary policy before, during, and after COVID-19 in the euro area and the United States using SVAR models with sign restrictions based on a New Keynesian framework. The analysis focuses on the effects of monetary shocks on overnight interest rates, inflation, and the output gap. The results show that, prior to the pandemic, monetary policy played a substantial role in shaping macroeconomic dynamics in the euro area, while real economic mechanisms were more dominant in the United States. During the COVID-19 phase, monetary stimulus became severely constrained by excess liquidity, heightened uncertainty, and a lack of viable investment opportunities. In the post-pandemic period, monetary policy regained prominence, producing stronger contractionary effects in the euro area and more moderate and heterogeneous responses in the United States. The findings highlight a clear asymmetry between the limited expansionary influence and the comparatively stronger restrictive power of monetary policy.

Keywords: Monetary policy, COVID-19, SVAR model, New Keynesian model, output gap, inflation, overnight interest rate, bayesian estimation

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Introduction

Although numerous authors have questioned the effectiveness of monetary policy in generating significant economic effects,[1] the reality is that adjusting benchmark interest rates remains one of the main tools used by governments and central banks around the world. Beyond the academic debate on the suitability of these measures, it is undeniable that, from the Victorian England portrayed by Walter Bagehot in *Lombard Street* to the contemporary United States of the Trump era, the interest rate set by the central bank occupies a central place in the arsenal of economic policy.

Given these circumstances, it is understandable that, as in this work, it is interesting to focus on the consequences that certain events have on the effectiveness of these policies, so present in macroeconomic daily life. More specifically, and given the close relationship that seems to exist between monetary demand—a key factor in determining the real and nominal effects of liquidity injections—and uncertainty, the objective of this study is to analyze the differences in the efficacy of monetary policy in the periods before, during, and after the global COVID-19 crisis. To enrich this comparison and highlight the structural conditions that influence this effectiveness, we will also divide the analysis between the United States and the European Union, with the aim of examining how underlying conditions on both sides of the Atlantic modify the efficacy of public policies.

To achieve the objective of this work, we have structured it into the following sections, following the usual procedure in econometric models of the *structural vector autoregression* (SVAR) type:

- First, we will establish a theoretical framework based on the simple New Keynesian (NK) model, from which we will extract the necessary theoretical restrictions to identify the structural shocks of the autoregressive model.

[1] John Maynard Keynes and many of his followers warned that, in recessionary contexts, economic agents tend to seek refuge in liquidity in response to uncertainty and in anticipation of rising interest rates. This behavior, they argued, could limit the effect of monetary injections, as they would be quickly absorbed by a high demand for money—a phenomenon known as the *liquidity trap*. For their part, the monetarists of the Chicago School, as well as later theorists such as advocates of rational expectations or real business cycles, cast doubt on the effectiveness of monetary policies due to the (progressive or immediate) adjustment of agents' expectations, which neutralized the real effects of money, especially in the long run.

- Second, we will collect and process data from the main macroeconomic indicators—output gap, inflation, and benchmark overnight interest rate—corresponding to the two economic areas of interest, in order to use them for building the models.

- Third, we will estimate three SVAR models for each economy (one for each time period) and obtain the main analytical tools:

  – Historical decomposition, which will attribute to each identified structural shock a specific contribution to the observed trajectory of each variable.

  – Impulse response functions, which will show the temporal impact of a monetary shock on the different macroeconomic variables.

- Fourth, based on the results obtained, we will compare the different combinations of economy and period, attempting to explain such results using economic reasoning and empirical evidence.

- Finally, we will offer a brief reflection on the role of monetary policy in the current macroeconomic environment, as well as a general conclusion based on the results of the previous analysis.

Before concluding this introduction and proceeding with the body of the work, I consider it appropriate to use this space to express my gratitude to the people and institutions that have made this study possible. First, I sincerely thank the project supervisor, Sergi Basco, not only for his corrections, comments, and suggestions—always rigorous and essential—but also for his patience and availability in resolving doubts and guiding this project. Second, I extend my thanks to my double-degree colleagues, Roger Aguilera, Adrià Camps, and Josep Escarré, for their constant feedback and comments that have contributed to improving and refining this work. Finally, I thank the research division of the *Federal Reserve Bank of St. Louis* for access to its database via API, without which much of the empirical analysis presented would not have been possible.

I LITERATURE REVIEW

I.1 Evolution of the VAR methodology

The methodology that inspires this work—and through which we hope to extract relevant conclusions about the behavior of the economy during the pandemic—has its origin in the work of Christopher A. Sims, specifically in his influential article *Macroeconomics and Reality* (1980). In this work, Sims criticized the excessive use of identification restrictions imposed by the dominant econometric models of the time. As an alternative, he proposed a methodology based on extending univariate autoregressive models—the classic AR(p)—to a multivariate setting. Instead of working with a single variable (a scalar), Sims proposed analyzing sets of variables (vectors), which gave rise to the development of vector autoregressive models, or VAR(p).

Building on Sims' seminal contributions, several economists—among whom Blanchard and Quah (1989), Shapiro and Watson (1988), Bernanke (1986), Galí (1992; 1999), and Sims himself (1986) stand out—began introducing restrictions through structural matrices, both in the short and long term, with the aim of identifying the underlying shocks behind the stochastic errors of VAR models. This new generation of models was dubbed structural vector autoregressive models, or simply SVARs. The reason for this methodological advance lies in the fact that, while VARs constituted a very suitable empirical tool for the dynamic description of time series, economic research is not satisfied with description: its fundamental objective is causal analysis. Therefore, the introduction of structural restrictions—both short-run and long-run—that allow distinguishing the effects of different types of shocks, became a particularly valued resource in economic research.

In order to avoid problems derived from the overparameterization of SVAR models and to improve their forecasting ability, some authors opted to identify autoregressive models by incorporating prior probability distributions, leveraging the implications of Bayes' Theorem. This new methodological orientation gave rise to the so-called Bayesian VARs, or BVARs. The works of Doan, Litterman and Sims (1984), as well as those of Litterman (1986), Sims and Zha (1998), and Uhlig (2005), constitute some of the most influential contributions in this line of research, which incorporates techniques such as hyperparameter tuning, sign restrictions, and the joint estimation of prior and posterior distributions. The adoption of these Bayesian tools substantially reduced the variance of the estimators and, consequently, improved the accuracy of forecasts. This decisively contributed to the hegemony of BVAR models, to the point that many of the major international monetary institutions began using them systematically in their analysis and projection exercises.

From the beginning of the millennium to the present day, the hegemony of VAR models, combined with the diversity of empirical challenges they have faced, has fostered the emergence of numerous variations in their formulation. The desire to extend the VAR methodology to databases with a large number of variables encountered the problem of dimensionality (curse of dimensionality), a challenge addressed through the development of FAVAR models (Factor-Augmented VAR), which synthesize the available information through latent factors and allow for more efficient estimations (Bernanke, Boivin, and Eliasz, 2005). On the other hand, Proxy SVARs, as proposed by Gertler and Karadi (2015), manage to identify structural shocks without the need to impose specific restrictions, using for this purpose estimation techniques based on Instrumental Variables (IV). Finally, the development of TVP-VARs (Time-Varying Parameter VARs) has allowed the analysis of extensive time series or those covering periods of high volatility, contexts in which the hypothesis of constancy of structural parameters is unsustainable (Cogley and Sargent, 2005; Primiceri, 2005).

We could continue enumerating variations and innovations of the VAR methodology that, from GVARs—designed to model the global economy based on links between different national economies—to DeepVARs—which integrate deep neural networks to estimate structural parameters—passing through MF-VARs—which allow working with variables of different time frequencies—have contributed significantly to refining empirical analyses and macroeconomic projections in recent decades. However, we consider that this brief introduction to the evolution of VAR models is sufficient to offer the reader a clear general view of their operation and relevance, and thus allows us to move on to the review of the literature that has used them in the analysis of the same subject matter that concerns us.

I.2 VAR models and monetary policy

The VAR methodology is not alien to the study of the effects of monetary policy. Without aiming to be exhaustive, it is evident that a significant number of the most relevant publications using these models have focused on studying the repercussions of monetary policy. Bernanke and Binder (1992) highlighted the federal funds rate as one of the most relevant indicators for capturing the impact of monetary policy, as reflected in their SVAR model. This indicator also acts as a transmission mechanism linking the decisions of monetary authorities with the evolution of the real economy. In fact, Uhlig (2005) inaugurated an agnostic identification scheme based on sign restrictions within the framework of an investigation into the effects of monetary policy on output. For his part, Sims (1992) examined specification errors that, in certain simple VAR models, could lead to a positive response of the inflation rate to a contractionary monetary policy shock. Along the same lines, Leeper et al. (1996) carried out a systematic analysis of various methods to isolate and identify monetary policy "innovations" or shocks, finally implementing the method they considered most appropriate in a BVAR-type model.

Nevertheless, the theoretical framework and the type of modeling we will adopt in this work are based on the outstanding study by Wolf (2020), which demonstrates the coherence between empirical results and reference theoretical models of New Keynesianism. Furthermore, this author proposes the incorporation of the Taylor Rule as a mechanism to reinforce identification through sign restrictions. Wolf's conclusions show that, indeed, the real impact of monetary policies is greater than is often acknowledged.

I.3 Analyses of monetary policy during COVID-19

In recent times, and although the literature is not yet abundant, several authors have continued this line of research with an objective similar to ours: studying the effects of monetary policy during the greatest economic contraction of the 21st century, that caused by COVID-19. Regarding works not produced by official institutions, probably the most relevant article is that of Feldkircher, Huber, and Pfarrhofer (2021), in which, using a mixed-frequency VAR model (MF-VAR), high and low-frequency data (weekly and monthly, respectively) are combined to simulate counterfactual scenarios of the absence of monetary policy. This allows assessing the real impact that these policies had during the pandemic period.

Another notable study is that of Yilmazkuday (2022), which investigates the impact of monetary policy taking into account the presence of lower bounds (zero bound limits) of official interest rates while comparing advanced economies with emerging economies.

Camehl and Woźniak (2023) use a BVAR model with time-varying parameters to show that, following the pandemic, a substantial change occurred in the underlying Taylor rule guiding the actions of central banks, which became more oriented towards monetary stimulus—a behavior the authors describe as a *money-augmented Taylor rule*.

Finally, and although its objective is not the study of monetary policy *per se*, the notable paper by Bernanke and Blanchard (2025) on the causes of post-pandemic inflation highlights—using a hybrid model that approximates SVARs but incorporates additional exogenous variables—the implications that government spending programs, expectations (through inflation anchoring), and labor market dynamics, among others, had in explaining the extraordinary price increases experienced by developed economies after COVID-19.

Regarding studies produced by financial and monetary institutions, we can begin by highlighting the working paper of the Federal Reserve Bank of Atlanta (FRB Atlanta), by Arias et al. (2024). In this work, using a sophisticated BVAR model with time-varying parameters and sign restrictions, the authors address the problems arising from the lack of quarterly data in the post-COVID period. They conclude that, although the Fed did not act with the necessary speed to adjust its monetary policies, its contribution to output growth was very limited.

Moving to the Federal Reserve Bank of Chicago, the study by King (2023) stands out, focusing on the effects of monetary policy on financial markets. Using a VAR model with sign restrictions and counterfactual analyses, King concludes that: (1) monetary policy was effective in stabilizing financial markets after the crisis, and (2) its effects are not limited exclusively to the impact on corporate profits or risk-free interest rates, but also affect the equity risk premium, improving confidence and reducing the perceived risk associated with private capital investments.

On the other hand, a recent study by the International Monetary Fund (IMF), produced by Barrett and Platzer (2024), employs a FAVAR model with high-frequency data to estimate monetary shocks, which are then introduced as instrumental variables (IV) in a Proxy SVAR to evaluate their effects on the main macroeconomic aggregates. The results suggest that both the transmission mechanisms and the speed of propagation of monetary shocks were approximately 25% slower during the post-COVID period compared to the pre-pandemic stage.

II THEORETICAL FRAMEWORK

As explained earlier, in order to isolate the effect of the various structural shocks that—ultimately—determine the evolution of the main macroeconomic variables, it is necessary to impose a series of restrictions that allow identifying these shocks from the error terms of the reduced-form VAR model. In our case, with the aim of identifying the perturbations associated with the monetary policy to which the analyzed economies were subjected, it is essential to previously specify what the fundamental characteristics of these shocks are. Only in this way can we adequately distinguish them from the rest of the perturbations that make up the vector of errors of the model.

Although the literature offers multiple approaches to the identification problem in SVAR models, the methodology adopted in this work—inspired by some of the most influential studies on the subject—is based on a theory-driven identification scheme. This strategy starts from the idea that, through the knowledge provided by economic theory, it is possible to establish *a priori* certain relationships between structural shocks and macroeconomic variables. By imposing these relationships on the data—either through structural matrices or, in the Bayesian context, through prior distributions—we can identify the shocks in a robust manner and interpret the evolution of the variables in structural terms. A classic example of this approach is found in the well-known work of Blanchard and Quah (1989), in which, assuming that demand shocks have no long-term effects on output, the authors manage to distinguish them from supply shocks. Thus, economic theory not only guides the construction of the model, but is also a key piece for its identification, as it allows us to infer how underlying shocks interact with the endogenous variables of the system.

In accordance with what has been stated so far, and given that monetary policy shocks constitute the main object of interest of this study, our immediate purpose is to provide a theoretical characterization that allows identifying them within the set of structural perturbations. To achieve this objective, we resort to the reference model in modern macroeconomics: the three-equation New Keynesian (NK) model, as presented by Jordi Galí (2015). In the following sections, we will develop this model from its microeconomic foundations, derive its equilibrium conditions, and establish the resulting system of equations.[1]

[1]It should be noted, by way of clarification, that the content of the following section lacks its own originality. It is essentially a reworking—albeit briefer—of the theoretical development presented by Galí (2015, chap.3).

II.1 The Basic New Keynesian Model

II.1.1 The household problem

We start with household behavior, assuming that they seek to maximize their expected intertemporal utility over an infinite horizon. This utility depends on both consumption C_t and the number of hours worked N_t in each period t, and is discounted by a discount factor β, reflecting time preference. Thus, the household objective function can be expressed as:

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t, N_t\right)$$

To establish the budget constraint faced by households in our model, it must be specified that, in fact, C_t is a consumption index formed by $C_t(i)$, that is, by the quantities of the i-th consumption good that the household consumes in period t. Each good has an associated price $P_t(i)$ that can vary by period. However, we consider not only consumption expenditures but also the possibility that agents save and invest, by purchasing one-period zero-coupon bonds, represented by B_t, acquired at price Q_t, where usually $Q_t \leq 1$, reflecting that bonds are sold at a discount or below par.

This intertemporal flow of expenditures is limited by the intertemporal flow of household income, which comprises: (1) the nominal return on bonds acquired in the previous period, B_{t-1}; (2) labor remuneration, which is the product of hours worked N_t and the hourly wage W_t; and (3) other secondary income sources, such as dividends or transfers, included in the generic term T_t.

Therefore, the household budget constraint is expressed by the following expression:

$$\forall t = 0, 1, 2, \ldots \mid \int_0^1 P_t(i) C_t(i) di + Q_t B_t \leq B_{t-1} + W_t N_t + T_t$$

As can be seen in Annex V.7, the solution associated with the posed optimization problem implies an allocation of resources such that, for all $i \in [0, 1]$, the level of consumption is:

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} C_t \tag{II.1}$$

where P_t represents the aggregate consumer price index, and $\epsilon > 1$ is the elasticity of substitution between differentiated goods. This expression implies that the demand for each good i is a decreasing function of its relative price with respect to the general price level. Under this optimal behavior, the expression $\int_0^1 P_t(i) C_t(i) di$ becomes equal to $P_t C_t$—that is, the product of the

However, any errors, inaccuracies, or incorrect interpretations that may be found therein are attributable exclusively to the author of this work.

aggregate consumption index and the aggregate consumer price index—. This simplification allows us to reformulate the household budget constraint in the following form:

$$P_t C_t + Q_t B_t \leq B_{t-1} + W_t N_t + T_t$$

Considering now the optimality conditions associated with labor supply and investment decisions, detailed in Annex V.8, and assuming an isoelastic utility function of the form: $U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\phi}}{1+\phi}$,[2] the optimal conditions can be log-linearized around the steady state and take the following form:

$$w_t - p_t = \sigma c_t + \phi n_t \tag{II.2}$$

$$c_t = E_t\{c_{t+1}\} - \frac{1}{\sigma}\left(i_t - E_t\{\pi_{t+1}\} - \rho\right) \tag{II.3}$$

where $i_t \equiv -\log Q_t$ is the nominal interest rate[3] and $\rho \equiv -\log \beta$ is the natural interest rate or discount rate.

II.1.2 The firm problem

Moving to the analysis of firm behavior, it should be noted that, within our theoretical framework, we will assume the existence of a continuum of firms indexed by $i \in [0, 1]$, each of which produces a quantity $Y_t(i)$ of the specific consumption good. The production of each firm is based on a Cobb-Douglas production function, which combines a common technological level A_t, shared by all firms, with a variable quantity of labor hours $N_t(i)$.

$$Y_t(i) = A_t N_t(i)^{1-\alpha}$$

Naturally, the volume of production of firms will depend largely on the prices they can obtain for the goods they manufacture; for this reason, the next step consists of describing the dynamics of price formation in this economy. Following the formalism proposed by Calvo (1983), which aims to capture the existence of nominal rigidities, we assume that each firm has, in each period, a probability $1 - \theta$ of being able to readjust its price, where $\theta \in (0, 1)$ represents the degree of price rigidity or *stickiness*. In this environment with rigid prices, and according to the results obtained in Annex V.9, the aggregate price dynamics can be described by the following

[2]In this expression $\sigma > 0$ is the coefficient of relative risk aversion and $\phi > 0$ regulates the disutility of labor

[3]Considering that the bond price Q_t is the discounted value of its face value, it is easy to see how we can arrive at this definition of the nominal interest rate:

$$Q_t = \frac{1}{(1 + i_t)} \implies \log Q_t = -\log(1 + i_t) \implies i_t \simeq -\log Q_t$$

equation:

$$\Pi_t^{1-\varepsilon} = \theta + (1-\theta)\left(\frac{P_t^*}{P_{t-1}}\right)^{1-\varepsilon} \tag{II.4}$$

Although in the previous expression we have introduced the term P_t^*, which represents the optimal price set by a firm if it has the opportunity to readjust its prices, we have not yet provided a formal definition, which we will correct next. In general terms, this optimal price is obtained by maximizing the firm's objective function, which reflects the expected present value of future profits generated while the set price remains in effect. Let $Q_{t,t+k} \equiv \beta^k (C_{t+k}/C_t)^{-\sigma}(P_t/P_{t+k})$ be the stochastic discount factor that captures time preference, risk aversion—expressed in terms of consumption goods substitution—, and the inflation premium, and let $\Psi_t(\cdot)$ be the cost function, the mathematical expression of the objective function is as follows:

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ Q_{t,t+k} \left(P_t^* Y_{t+k|t} - \Psi_{t+k}(Y_{t+k|t}) \right) \right\}$$

This firm optimization problem is necessarily subject to the constraint imposed by the demand expression faced by each firm.

$$Y_{t+k,t} = \left(\frac{P_t^*}{P_{t+k}}\right)^{-\varepsilon} C_{t+k}$$

Without going into excessive technical details, the first-order condition associated with this optimization problem takes the following form:

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ Q_{t,t+k} Y_{t+k|t} \left(\frac{P_t^*}{P_{t-1}} - \mathcal{M} MC_{t+k|t} \Pi_{t-1,t+k} \right) \right\} = 0 \tag{II.5}$$

where $\mathcal{M}$ is the optimal markup that a firm would apply in the absence of price adjustment rigidities, and $MC_{t+k|t}$ is the real marginal cost in period $t+k$ for a firm that last set its price in period t. Basically, this expression indicates that, to maximize its market value, each firm will try to set a price P_t^* such that it equals its future marginal cost multiplied by the optimal markup.

To conclude this section, and considering that—in the short term—modern economies seem to operate around a steady state characterized by inflation close to zero (*zero inflation steady state*), it is pertinent—for the analysis of equilibrium—to approximate the previous expression using a first-order Taylor expansion. This approximation allows us to linearize the optimal price-setting equation and thus obtain a more tractable representation of the aggregate price dynamics in response to small perturbations:

$$p_t^* - p_{t-1} = (1-\beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \widehat{mc}_{t+k|t} + (p_{t+k} - p_{t-1}) \right\} \tag{II.6}$$

Here $\widehat{mc}_{t+k|t} \equiv mc_{t+k|t} - mc$ represents the log-deviation of marginal cost from its steady-state value, which is nothing other than the logarithm of the optimal markup: $mc = -\mu \equiv \log \mathcal{M}$.

II.1.3 Equilibrium

Although we have considered it appropriate to go into detail on the microeconomic assumptions and present the optimization problems that lead to the fundamental equations of the model—with the aim of justifying their logical and economic robustness—we estimate that it is not necessary to exhaustively describe the procedure by which the general equilibrium of the system is achieved. Thus, we will limit ourselves to stating the conditions that define this equilibrium, which are summarized in the fact that, in each period, the goods and labor markets must clear completely, as reflected in the following two equalities.

$$\text{Equilibrium in the goods market}: \forall t, i \in [0,1] \mid Y_t(i) = C_t(i) \Leftrightarrow \forall t \mid Y_t = C_t$$

$$\text{Equilibrium in the labor market}: \forall t \mid N_t = \int_0^1 N_t(i)di$$

The first of the equilibrium equations, which results from imposing the equilibrium conditions on the equations developed in the previous subsections, is that referring to the inflation rate π_t, defined as the rate of change of the aggregate price index.

$$\pi_t = \beta E_t \{\pi_{t+1}\} + \kappa \tilde{y}_t - \sigma^s \varepsilon_t^s \tag{II.7}$$

As this equation shows, current inflation depends positively on future inflation expectations, discounted by the time preference rate, $\beta E_t \{\pi_{t+1}\}$. When agents anticipate an increase in future prices, they tend to bring forward purchases and postpone sales, which puts upward pressure on the general price level in the present.[4] Furthermore, inflation also responds to the output gap $\tilde{y}_t$—that is, the difference between real GDP and potential GDP in logarithmic terms—: when economic activity exceeds its sustainable level due to causes such as expansionary fiscal policy or a monetary injection, bottlenecks arise in production processes, which increases marginal costs and, consequently, prices (Huerta de Soto, 2023, 319). Finally, the equation incorporates a perturbation term $\varepsilon_t^s \sim N(0,1)$, which captures exogenous supply shocks that can affect inflation, such as temporary supply crises in key raw materials, like oil.

The second equilibrium equation refers to the output gap, the description of which we have

[4]In the words of Alfred Marshall (1907, 594):

> For when prices are likely to rise, people rush to borrow money and buy goods, and thus help prices to rise [...] When afterwards credit is shaken and prices begin to fall, everyone wants to get rid of commodities and get hold of money which is rapidly rising in value; this makes prices fall all the faster.

already provided in the previous paragraph:

$$\tilde{y}_t = E_t\{\tilde{y}_{t+1}\} - (i_t - E_t\{\pi_{t+1}\}) + \sigma^d \varepsilon_t^d \tag{II.8}$$

This expression reflects that the current level of economic activity depends, first, on expectations about future activity $E_t\{\tilde{y}_{t+1}\}$. This dependence is explained by the intertemporal behavior of consumers, who tend to smooth their consumption over time to avoid sharp fluctuations from one year to the next (Friedman, 1957, 20-31). Thus, if agents anticipate an improvement in economic conditions—and, therefore, an increase in future income—they are likely to bring forward some future consumption, increasing current aggregate demand. Symmetrically, in anticipation of an economic contraction, they may reduce current consumption to increase savings. Second, the output gap also responds to the real cost of credit, represented by the ex ante real interest rate, $i_t - E_t\{\pi_{t+1}\}$. When this increases, the financing of consumption and investment becomes more expensive, which reduces aggregate demand and, by extension, economic activity. Conversely, a lower real interest rate favors the expansion of demand. Finally, the perturbation term $\varepsilon_t^d \sim N(0,1)$ captures the impact of unexpected changes in intertemporal consumption preferences, which can modify both saving and investment and, consequently, affect the output gap.

II.1.4 The monetary policy rule

The last element we need to complete the basic NK model is the equation corresponding to the monetary policy rule. As shown by the studies of John B. Taylor (1993), although it is true that, *a priori*, central banks and other monetary authorities have the power to set interest rates in a discretionary manner, empirical evidence shows that, in practice, these institutions tend to follow systematic patterns. Instead of relying on arbitrary decisions by monetary policymakers, the determination of the benchmark interest rate seems to obey a specific rule, known as the Taylor Rule:

> What is perhaps surprising is that this rule fits the actual policy performance during the last few years remarkably well. [...] In this sense the Fed policy has been conducted as if the Fed had been following a policy rule much like the one called for by recent research on policy rules. (Taylor, 1993, 202-203)

Over time, the original formulation of the Taylor Rule has undergone various modifications that have refined its theoretical and empirical application, reaching the contemporary form used by Jordi Galí (2015, 50):

$$i_t = \phi_\pi \pi_t + \phi_y \tilde{y}_t + \sigma^m \varepsilon_t^m \tag{II.9}$$

Under conventional hypotheses, which assume $\phi_\pi > 1$ and $\phi_y \geq 0$, the Taylor Rule establishes, first, that the monetary authority reacts by raising interest rates in response to increases in the inflation rate. Given that a sustained increase in consumer goods prices constitutes an unfavorable macroeconomic scenario—especially for consumers with fixed incomes—central banks tend to respond by tightening credit conditions. This translates into a contraction in the volume of loans destined for consumption and investment, which reduces aggregate demand and, with it, upward pressure on prices. The higher the value of ϕ_π, the more intense the monetary policy response will be to increases in the general price level, and vice versa. Second, the part of the equation that could be described as "countercyclical" reflects the central bank's desire to keep output around its natural level. Thus, in contexts of economic prosperity, when real GDP exceeds its sustainable level, the monetary authority will increase interest rates to moderate activity and contain possible inflationary tensions. Conversely, in situations of economic weakness, where GDP is below its potential level, the central bank will lower interest rates to stimulate aggregate demand and favor the recovery of activity. Finally, the perturbation term $\varepsilon_t^m \sim N(0,1)$ captures random deviations—and, under standard assumptions, normally distributed—of monetary policy from the systematic rule. These deviations may be due, for example, to discretionary actions related to the management of international reserves, interventions on the exchange rate, or adjustments in the central bank's balance sheet in response to extraordinary circumstances.

II.1.5 Final formulation of the model

After all the previous mathematical development, and combining the different results obtained within such development, the NK model allows us to represent the aggregate behavior of the economy through a system of three fundamental equations. This system is formed, first, by the IS equation (Investment-Savings), which describes the intertemporal consumption relationship and captures the behavior of aggregate demand; second, by the New Keynesian Phillips Curve (NKPC), which expresses the dynamics of aggregate supply as a function of price rigidity and inflation expectations; and, finally, by the Taylor Rule (TR), which defines the systematic response of monetary policy—with an essentially stabilizing objective—to deviations of inflation and output from their desired levels. Formally:

$$\begin{cases} \tilde{y}_t & = E_t\left\{\tilde{y}_{t+1}\right\} - \left(i_t - E_t\left\{\pi_{t+1}\right\}\right) + \sigma^d \varepsilon_t^d \\ \pi_t & = \beta E_t\left\{\pi_{t+1}\right\} + \kappa \tilde{y}_t - \sigma^s \varepsilon_t^s \\ i_t & = \phi_\pi \pi_t + \phi_y \tilde{y}_t + \sigma^m \varepsilon_t^m \end{cases}$$

This final model is clearly static, and admits a closed solution given by the following matrix equation (Wolf, 2020, 7):

$$\begin{pmatrix} \tilde{y}_t \\ \pi_t \\ i_t \end{pmatrix} = \frac{1}{1+\phi_y+\phi_\pi\kappa} \begin{pmatrix} \sigma^d & \phi_\pi \sigma^s & -\sigma^m \\ \kappa\sigma^d & -(1+\phi_y)\sigma^s & -\kappa\sigma^m \\ (\phi_y+\phi_\pi\kappa)\sigma^d & -\phi_\pi\sigma^s & \sigma^m \end{pmatrix} \begin{pmatrix} \varepsilon_t^d \\ \varepsilon_t^s \\ \varepsilon_t^m \end{pmatrix} \tag{II.10}$$

II.2 Derivation of structural restrictions

II.2.1 A theory-driven agnostic identification procedure

As indicated at the beginning of the chapter, the theoretical framework provided by the three-equation NK model allows us to offer a formal characterization that facilitates the identification and differentiation of monetary policy shocks from other possible structural shocks.

First, and without going into too much detail, although it is completely true that supply and demand shocks are the subject of study of this work, we have considered it appropriate to characterize them with the main objective of avoiding that some of their effects may be confused with those of the monetary policy shocks that interest us. This is because, for example, under certain circumstances an expansionary demand shock can generate impacts on the main macroeconomic variables very similar to those of an expansionary monetary policy shock, such as an increase in the inflation rate and a temporary reduction in interest rates.

Similarly, a negative supply shock, which increases the inflation rate by reducing the quantity of goods available and reduces interest rates due to the relative oversupply of credit from lenders relative to borrowers (entrepreneurs), could also be confused with an expansionary monetary shock.

Therefore, guided by the matrix system, we consider that demand shocks ε_t^d are those that, at least temporarily, increase both the output gap and the inflation rate, while supply shocks ε_t^s, of a more persistent nature, tend to increase the output gap and decrease the growth rate of the general price level:

$$\frac{\partial \pi_t}{\partial \varepsilon_t^d} = \frac{\kappa \sigma^d}{1 + \phi_y + \phi_\pi \kappa} \geq 0 \quad \text{and} \quad \frac{\partial \tilde{y}_t}{\partial \varepsilon_t^d} = \frac{\sigma^d}{1 + \phi_y + \phi_\pi \kappa} \geq 0$$

$$\frac{\partial \pi_t}{\partial \varepsilon_t^s} = \frac{-(1 + \phi_y)\sigma^s}{1 + \phi_y + \phi_\pi \kappa} \leq 0 \quad \text{and} \quad \frac{\partial \tilde{y}_t}{\partial \varepsilon_t^s} = \frac{\phi_\pi \sigma^s}{1 + \phi_y + \phi_\pi \kappa} \geq 0$$

Second, regarding the definition of monetary policy shocks, represented by ε_t^m, we consider that their distinctive feature lies in the fact that «a "contractionary" monetary policy shock does not lead to increases in prices, [...] or decreases in the federal funds rate for a certain period following the shock» (Uhlig, 2005, 384). From the equilibrium solution of the NK model, and considering the partial derivatives with respect to this shock, we obtain:

$$\frac{\partial \pi_t}{\partial \varepsilon_t^m} = \frac{-\kappa \sigma^m}{1 + \phi_y + \phi_\pi \kappa} \leq 0 \quad \text{and} \quad \frac{\partial i_t}{\partial \varepsilon_t^m} = \frac{\sigma^m}{1 + \phi_y + \phi_\pi \kappa} \geq 0$$

These expressions allow us to state that the impact of a contractionary monetary shock on the inflation rate will not be positive, and that, simultaneously, overnight interest rates will not decrease, but will tend to increase.

Additionally, if we assume—as is common in the literature—that the different structural shocks, including that of monetary policy, follow an autoregressive dynamic of the type $AR(p)$,

$$\varepsilon_t^m = \theta_1 \varepsilon_{t-1}^m + \theta_2 \varepsilon_{t-2}^m + \ldots + \theta_p \varepsilon_{t-p}^m = \sum_{i=1}^{p} \theta_i \varepsilon_{t-i}^m$$

then it is reasonable to expect that the effects associated with this shock will persist over a certain time horizon. Therefore, the imposed sign restrictions should not be applied only at the initial instant t, but must be extended to a set of subsequent periods $h = 0, \ldots, H$.

It is precisely this minimalist approach to structural restrictions—where no statement is made about the magnitude or nullity of the effects, but only about their sign—that justifies the designation of "agnostic" for this identification procedure.

As we will argue in chapter IV, it is possible to invert a VAR model to describe the dynamics of the endogenous variables $y = \{\tilde{y}, \pi, i\}$ as an infinite moving average process $MA(\infty)$. This implies that these variables can be expressed as an infinite linear combination of the lags of the perturbation vector ϵ_t. In this context, the imposition of structural restrictions consists of establishing that, during the first $h = 0, \ldots, H$ periods, the relationship between the structural shocks ε_t and the stochastic errors (and the variables of interest) is defined by the following expression, based on impulse response functions (IRF $\equiv \tilde{\Psi}$):

$$\forall h = 0, \ldots, H \quad | \quad \text{sign}\left(\tilde{\Psi}_h^{\varepsilon^m}\right) = \begin{pmatrix} ? \\ - \\ + \end{pmatrix}$$

This causes that, *a priori*, the effects of monetary policy shocks on the endogenous variables have the following characteristics:

$$\forall h = 0, \ldots, H \quad | \quad \frac{\partial \pi_{t+h}}{\partial \varepsilon_t^m} \leq 0 \quad \text{and} \quad \frac{\partial i_{t+h}}{\partial \varepsilon_t^m} \geq 0$$

II.2.2 Support from other schools of thought

Before proceeding with the justification of why it has been considered preferable to leave the impact of monetary policy on the output gap unrestricted—an issue we will address in the next subsection—I hope to be allowed a brief methodological digression in favor of an exercise of intellectual eclecticism. And it is that, usually, once the theoretical framework is established and the restrictions that should allow the identification of structural shocks are extracted from it, many authors are satisfied and move directly to the formulation and estimation of the corresponding econometric models. Although this way of proceeding may be, in many cases, methodologically valid, it can also entail a risk: that of basing the identification process exclusively on a single theoretical model, ignoring the diversity of perspectives existing within economic thought.

Economics, by its very nature, is a plural and controversial discipline, in which multiple analytical traditions coexist, each with its own assumptions, language, and deductive structure. This implies that predictions about the effects of the same shock can vary considerably depending on the conceptual framework adopted. In this context, limiting oneself to justifying structural restrictions based on a single approach can mean a loss of theoretical richness and a reduction in scientific rigor. For this reason, I believe that, if one wants to endow the identification restrictions with the maximum degree of robustness and epistemological legitimacy, it is convenient to show that these are not only consistent with a specific theoretical model—possibly orthodox—but can also be compatible with the principles of other schools of thought, even those furthest from the conventional view.

In light of these considerations, I have considered it opportune to briefly expose that our characterization of the effects of monetary policy does not respond solely to the demands of the New Keynesian paradigm, but is also compatible with the conceptual framework of most schools of economic thought throughout history. This transversal coincidence reinforces the legitimacy of the adopted restrictions and demonstrates that the diagnosis we present is not exclusive to a particular orthodoxy, but is based on a broader and historically informed theoretical view.

Beginning with the great historical detractors of Keynesianism, it should be noted that the main referent of monetarism and prominent figure of the Chicago School, Milton Friedman (1968, 7-8), maintained—in clearly Wicksellian terms—that: «the monetary authority can make the market rate less than the natural rate only by inflation. It can make the market rate higher than the natural rate only by deflation». And indeed, despite his recognized adherence to the principle of monetary neutrality in the long term, monetarists were fully aware of the real effects that monetary policy could generate in the short term; they understood that an artificial reduction of interest rates—that is, below their natural level—could only be sustained through an increase in the growth rate of the general price level.

Continuing with other typically liberal traditions, it should be said that theorists of the Austrian School seem to share a characterization quite similar to ours regarding the effects of monetary policy. More concretely, in his work *Prices and Production*,[5] Friedrich von Hayek (2008, 320-

[5]It is especially suggestive to observe that the collection in which this work is included—titled *Prices and Production and Other Works* and edited by the Ludwig von Mises Institute—has a preface written by one of the main exponents and developers of the methodology of structural VARs: Danny Quah.

321), referring to the process of credit expansion induced by the reduction of official interest rates, stated: «even if these obstacles to credit expansion were absent, such a policy would, sooner or later, inevitably lead to a rapid and progressive rise in prices [...] It is only a question of time when this general and progressive rise of prices becomes very rapid».

Moving on to authors more critical of the market economy and distant from the *economic mainstream*, it should be noted that, despite their reluctance to use mathematical models and quantitative methodologies, post-Keynesians seem to share our conception of monetary policy. In his *magnum opus*, Hyman Minsky (1986, 285-286) draws a clear causal link between the increase in investment—often stimulated by reductions in interest rates set by monetary authorities—and inflationary processes:

> In our economy the causal chain that leads to inflation starts with rising investment or government spending, which leads to increases in markups; an increase in the money supply or in money velocity usually is associated with the rise in investment or government spending. Investment demand rests upon the availability of financing.

We hope that the brief compilation of quotes we have just presented contributes to theoretically reinforcing the restrictions on which we will build our future econometric model. In view of this collection of schools and authors, it seems that the majority opinion within the economic profession leans in favor of our description of the main characteristics of economic policy. Beyond some theorists of rational expectations, who dismiss the nominal rigidities that inevitably characterize our economic systems—these theorists often associated with New Classical Macroeconomics—most economists agree with our position.

II.2.3 Reasons for not restricting the response of output

As we have just demonstrated, everything we have established so far—including the decision to identify monetary shocks through sign restrictions on short-term interest rates and the inflation rate—is fully aligned with both the corpus of macroeconomic *mainstream* and more heterodox perspectives. However, some readers may wonder why, if stimulating economic activity and employment constitutes one of the fundamental objectives of monetary policy, no sign restriction has been imposed on the response of monetary shocks in relation to the output gap. Certainly, the coefficients of equation (II.10) suggest that, *a priori*, one of the main effects of monetary stimuli is the increase in aggregate income, through channels such as financing facilities (which boost investment and consumption) and the improvement of business profit margins (which stimulate productive activity). Nevertheless, we consider that there are sufficient empirical and theoretical arguments to dispense with a sign restriction on the output gap when identifying monetary shocks.

First, it must be understood that imposing restrictions is not innocuous. Even if the positive impact of monetary policy on the output gap were a prominent characteristic of this type of shocks, we would still need to be cautious with the abuse of structural restrictions in a model like ours. Identification restrictions, although essential to capture fundamental shocks and carry out causal analysis, in fact represent an imposition of *ex ante* criteria on the data. This can bias the results and make us lose relevant empirical information, especially if we multiply restrictions beyond what is strictly necessary.

Although, in general, it may seem reasonable to assume a positive effect of monetary policy on the output gap, empirical research shows us that, in reality, «monetary policy shocks are not important drivers of any *individual* macro aggregate, but they induce highly atypical *co-movement* patterns. Notably, monetary policy shocks are unique in that they push interest rates and inflation in opposite directions» (Wolf, 2020, 10). In more detail, recent empirical studies have shown that the $R^2_{0,m}$,[6] calculated in large bivariate VAR models with (π_t, i_t), is quite high (with values close to 0.78) and does not seem to improve with the incorporation of the variable $\tilde{y}_t$ (Smets and Wouters, 2007, 37). This fact reinforces the idea that the essential characteristic of monetary shocks lies in causing co-movements of inflation and interest rates.

Thus, if we can identify monetary perturbations with great precision simply from the co-movement between these two variables, what reason would there be to add potentially superfluous restrictions? Doing so could unnecessarily restrict our model and prevent us from capturing relevant interactions between monetary shocks and the level of income.

Second, and now entering purely theoretical considerations, it must be kept in mind that the correlation between monetary shocks and the output gap may not be as evident as it might seem at first glance, especially if some of the fundamental assumptions underlying the NK model are relaxed. Although the scenarios that will be described below are compatible with a sign restriction identification scheme applied to the output gap—since they simply imply that $\frac{\partial \tilde{y}_t}{\partial \varepsilon_t^m} = 0$—the fact is that situations such as the liquidity trap, widespread deleveraging (that is, massive debt repayment by economic units to lighten their balance sheets), inflationary expectations with little time lag, or high uncertainty (especially plausible in periods like the COVID-19 crisis) can render liquidity injections or credit facilities provided by monetary authorities sterile.

However, more extreme—but no less relevant—scenarios such as lack of confidence in the economy or in the currency itself can cause monetary stimuli, far from being interpreted as a signal of revival, to be perceived as a symptom of structural weakness, either of the economy

[6] This metric, the expression of which is (Wolf, 2020, 27):

$$R^2_{0,m} = \mathrm{Cov}(u_t, \varepsilon_t^m)' \times \mathrm{Var}(u_t)^{-1} \times \mathrm{Cov}(u_t, \varepsilon_t^m).$$

indicates to what extent the structural monetary shock ε_t^m explains the variability of the forecast error of the reduced-form VAR. That is, it allows seeing to what extent this shock contributes to the variation of the variables of a given VAR model (in this case, the interest rate and the inflation rate).

or of the monetary system. This perception can depress expectations, erode confidence, and end up harming both consumption and investment. Although these scenarios may seem hardly applicable to developed economies with solid institutional systems—such as the United States or the European Union—the evidence of the positive impacts of Javier Milei's expansionary austerity policy in Argentina—based, in part, on restrictive monetary policy—shows that these situations are not only theoretically possible, but also an observable economic reality.

The manifest superfluity that would be involved in incorporating additional identification restrictions on monetary shocks—such as a predetermined response of the output gap—combined with the risk that these restrictions are dissonant with the specific economic dynamics of the COVID-19 stage, as well as the possibility that they become relevant empirical omissions or interpretative biases, are the reasons that, ultimately, have led us to discard their implementation within our models.

III DATA

III.1 Variables

Taking into account the theoretical framework with which we are working, it is clear that the variables that will be part of our econometric model must correspond to the three central variables of the three-equation NK model, namely: the overnight interest rate, inflation rate, and output gap.

III.1.1 Overnight interest rate

The overnight interest rate is the short-term interest rate at which, as its name indicates, credit operations with a maturity of one day are negotiated. Among the most common examples of these operations are interbank loans, reverse REPOs (repurchase agreements), or the use of credit facilities provided by central banks. Given the large number of overnight operations carried out daily—and the diversity of interest rates at which they are executed—we will use aggregate indicators that synthesize this activity. In particular, we will use the Effective Federal Funds Rate for the United States, and EONIA or €STR for the Eurozone, which reflect the weighted average by trading volumes of interest rates in the respective interbank markets.

From the point of view of economic theory, the overnight interest rate constitutes the main instrument for transmitting monetary policy to the real economy (Bernanke and Blinder, 1992). Through adjustments in the official interest rate (set by central banks, and which should not be directly confused with the observed interbank interest rate), the liquidity conditions of the system are modified. This alters the opportunity cost of financial institutions—that is, the return they obtain for holding reserves at the central bank—which can encourage them to increase credit offered to firms and households (in case of a reduction in the rate) or, conversely, to restrict it (in case of an increase). Through this indirect transmission mechanism, monetary policy aims to modulate the pace of economic activity by changing the financing conditions for the main economic agents (Mehrling, 2011, 25-29).

III.1.2 Inflation rate

The inflation rate is defined as the rate of change of the general price level in an economy. In other words, it indicates the rate at which the prices of goods and services consumed by households grow (or decrease). If we denote the general price level in period t by P_t, the inflation rate π_t of that period (expressed as a percentage) can be calculated as:

$$\pi_t = \frac{P_t - P_{t-1}}{P_{t-1}} \cdot 100$$

Although there is no single way to measure the price level, it is common to do so using consumer price indices. These indices reflect the evolution of the price of a representative basket of goods and services typically purchased by households, weighting each component according to its relative weight in consumption. Thus, products with a higher weight within household spending have a greater impact on the overall index. In the case of Spain, the indicator used is the Consumer Price Index (CPI), compiled by the National Statistics Institute (INE); in the European Union, the reference is the Harmonized Index of Consumer Prices (HICP), compiled by Eurostat; and in the United States, the Consumer Price Index (CPI) is used, published by the Bureau of Labor Statistics.

From a macroeconomic point of view, inflation can be caused by various factors. From the demand side, a sustained increase may reflect an excess of aggregate expenditure—both public and private—that puts upward pressure on prices. From the supply side, negative shocks, such as rising raw material prices or disruptions in supply chains, can raise production costs and, consequently, final prices. From the monetary perspective, inflation can be interpreted as a depreciation of the monetary unit relative to the set of available goods and services, and can have its origin, *ceteris paribus*, in an increase in the money supply (ΔM), a fall in the demand for money (i.e., an increase in its velocity of circulation, ΔV), or a reduction in the volume of output (∇Q), according to the classical formulation of the quantity equation $M \cdot V = P \cdot Q$. Finally, from the exchange rate perspective, inflation can also be a consequence of the devaluation of the national currency relative to other currencies. In this case, fluctuations in exchange rates arising from balance of payments imbalances or international capital flows can increase the cost of imports and, therefore, put upward pressure on domestic prices.

III.1.3 Output gap

Popularized by New Keynesian Macroeconomics models, the concept of output gap refers to the difference between the real GDP of an economy and its potential GDP at a given point in time. According to theory, every economy has a maximum production capacity, known as potential GDP. However, cyclical factors can cause the level of economic activity to be temporarily above or below this threshold. The output gap is precisely the metric that captures these deviations from the natural level of production (Blanchard and Galí, 2010, 36-37).

Given that potential GDP—an indispensable metric for computing the output gap—is an unobservable magnitude, various economic institutions have developed complex methodologies to estimate it. Among the most relevant estimates are those produced by the US Bureau of Economic Analysis and the Directorate-General for Economic and Financial Affairs of the European Commission (collected in the AMECO database). Nevertheless, economists also have more accessible and quite robust methods for estimating the output gap without needing to resort to complex models developed by large international institutions.[1]

From a macroeconomic perspective, deviations of real GDP from its potential level can be due to multiple factors, although they are often associated with expansions or contractions of economic activity. A severe financial crisis that causes the bankruptcy of banking institutions, the destruction of part of savings, and the restriction of credit will likely cause the productive system to operate below its capacities. Conversely, a fiscal or monetary stimulus can lead, temporarily, to a situation of economic overheating, where activity exceeds the usual productive capacity, exhausting idle resources and generating a context of relative "overproduction."

III.1.4 Periods

Once the endogenous variables that will form part of our econometric model have been defined, it is essential to establish the study periods that will structure the empirical analysis. These periods will serve both to delimit the relevant time intervals and to divide the statistical sample, thus allowing the estimation of the six final models.

Following the classification advanced in the introduction, we distinguish three broad time stages: *pre-COVID*, *COVID*, and *post-COVID*. Although their conceptual distinction is apparent—as they are organized around the COVID-19 health crisis—the fundamental challenge lies in selecting time intervals that most faithfully reflect the particular economic conditions of each period. In other words, we must carefully choose, and in accordance with the facts, time intervals that correspond as faithfully as possible to the three stages we are describing and that, therefore, allow us to adequately isolate the structural changes brought about by the pandemic.

It is for this reason that the selection of time segments has been guided by both chronological and economic criteria. The following table presents the delimitation adopted for each period, accompanied by a brief justification for its selection:

[1] For a clear exposition of the most common methods, see Brouwer (1998).

Period	Time interval	Justification
Pre-COVID	February 2014 – December 2019	This period reflects a stage of stable macroeconomic recovery in the Eurozone, following the Great Recession and the sovereign debt crisis. By the end of 2019, although the pandemic had already begun in Asia, its effects were not yet clearly perceived in Western economies.
COVID	January 2020 – March 2023	This interval covers the most disruptive phase of the pandemic. It includes global lockdowns, the sudden fall in GDP, and the subsequent expansive response in fiscal and monetary terms. Until mid-2023, restrictions were gradually lifted, mass vaccination completed, and policies shifted towards a clearly anti-inflationary orientation.
Post-COVID	April 2023 – Present	This period is identified with the phase of monetary normalization and structural readjustment. From 2023 onwards, economic policies ceased to focus on countering the immediate effects of the health crisis and turned to managing the consequences derived from previous expansionary policies. However, this stage of transition and rebalancing persists to this day.

Table III.1: Temporal delimitation of analysis periods

III.1.5 The frequency issue

Despite initially intending to follow the bulk of the literature by constructing models with quarterly temporal frequency data, we quickly encountered a series of obstacles that led us to reconsider this initial decision.

The main problem, also shared by other studies on the pandemic (Arias et al., 2024), is that, especially for the COVID and post-COVID periods, there was a notable lack of quarterly data. The relatively short duration of both time intervals translates into a scarcity of observations that made model estimation considerably difficult, with unsatisfactory adjustments. Precisely for this reason, studies such as those by Feldkircher, Huber, and Pfarrhofer (2021), King (2023), or Barrett and Platzer (2024) opted for the use of high-frequency data (daily or weekly) or monthly frequency, in order to increase the sample size and obtain more robust estimates of the structural parameters of their models.

Faced with this same problem, and inspired by the solutions adopted in recent literature, we decided to work with monthly data. This change tripled the number of observations available for each period and improved the statistical quality of the estimates. While it was relatively straightforward to obtain monthly series for the inflation rate and interest rates, the frequency transformation posed a challenge in the case of the output gap. Unlike the other two variables, the output gap is mostly available at quarterly frequency (as in the case of the United States) or annual frequency (in the case of the European Union).

To overcome this limitation, we considered two alternatives: interpolating the quarterly output gap series to convert it to monthly, or using a substitute variable (proxy) that adequately captured the underlying behavior of aggregate economic activity. Given that quarterly interpolation involved the loss of capacity to capture the rapid fluctuations that occurred during COVID-19, we opted for the second route: using the monthly Industrial Production Index (IPI) for both the European Union and the United States as a proxy for real GDP.

Although the IPI excludes components such as services or international trade—which represent a significant part of GDP—its high correlation with real GDP allows us to infer, with reasonable accuracy, the trends in economic activity. As will be explained in the following subsection, and following the advice of the supervisor of this work, this variable was transformed by subtracting its linear trend, with the aim of replicating the format of the output gap.

III.2 Transformations

Following the specialized literature and the established theoretical framework, we begin this section dedicated to variable transformations by noting that, in fact, the variables associated with the overnight interest rate i_t (EONIA, €STR, and Fed Funds) have not been transformed, but have been kept in levels, that is, in their original format.

In contrast, the rest of the variables—those related to the general price level P_t (CPI and HICP) and the industrial production index or real output Y_t (IPI)—have been subjected to a first transformation, consisting of applying the natural logarithm:

$$p_t = \log P_t \quad \text{and} \quad y_t = \log Y_t \tag{III.1}$$

The result of this transformation, which we denote using lowercase letters, not only allows us to have variables compatible with the log-linear form of the equilibrium equations of the NK model, but will also facilitate the final transformations with which we will obtain the definitive variables of the model.

Once prices and production have been transformed using the logarithm, only an additional calculation remains to obtain the two key variables of our model: the inflation rate and the output gap. In particular, to obtain inflation from the price level, we use a fundamental property of logarithms. Thus, inflation can be approximated by the first difference of the logarithm of the price level. Given that, for small values of x, it holds that $\log(1 + x) \approx x$, we can write:

$$p_t - p_{t-1} = \log P_t - \log P_{t-1} = \log\left(\frac{P_t}{P_{t-1}}\right) \approx \frac{P_t - P_{t-1}}{P_{t-1}} = \pi_t \tag{III.2}$$

Moving on to the computation of the output gap—and as already mentioned earlier—while there was the possibility of using relatively complex methods for its estimation (such as Hodrick-Prescott in its univariate or multivariate version, unobserved components models, or methods based on the production function), the good results obtained using the simple linear trend method led us to choose this approximation over other more sophisticated alternatives.

Specifically, this approach consists of approximating the potential level of GDP or IPI from the linear trend of this series, estimated over the period from 1999 to the present. This procedure is based on the assumption that there is a natural level of production around which economic activity fluctuates transitorily. Therefore, once the trend has been estimated using a linear model of the type $y = mx + n$, we obtain the output gap $\tilde{y}_t$ by subtracting the logarithm of the trend value y_t^n from the logarithm of the observed value y_t:

$$\tilde{y}_t \equiv y_t - y_t^n = \log Y_t - \log Y_t^n \tag{III.3}$$

where,

$$Y_t^n \approx \hat{\alpha} + \hat{\beta} t$$

such that $\hat{\alpha}$ and $\hat{\beta}$ are the Ordinary Least Squares estimators of the parameters of the linear model.

With this last transformation, we already have all the necessary variables for model estimation, the characteristics of which are summarized in Table III.2.

Table III.2: Variables used, sources, and transformations

Economy	Variable	Source	Transformation
United States			
USA	Overnight interest rate (Fed Funds Rate)	Federal Reserve Board	Level
	Inflation rate (Consumer Price Index)	Federal Reserve Board	Log Diff
	Output gap (Industrial Production Index)	Federal Reserve Board	Log Diff (relative to linear trend)
European Union			
EU-27	Overnight interest rate (EONIA Rate)	European Central Bank	Level
	Overnight interest rate (€STR)	European Central Bank	Level
	Inflation rate (Harmonized Index of Consumer Prices)	Eurostat	Log Diff
	Output gap (Industrial Production Index)	Eurostat	Log Diff (relative to linear trend)

III.3 Integration analysis

Before proceeding with the elaboration of the models, and with the aim of specifying them adequately, it is necessary to stop and study some of the properties of the time series we are working with; more specifically, their order of integration. This property is especially relevant, because if we encounter processes with a unit root or greater, i.e., non-stationary in mean and/or variance, the results and statistical properties of our estimates could be seriously compromised.

However, before analyzing this property, it is appropriate to make a brief theoretical review to concisely define what it consists of.

III.3.1 Order of integration

A stochastic process x_t is said to be integrated of order d, $x_t \sim I(d)$, if its d-th difference $\Delta^d x_t$ describes a stationary process, i.e., with zero order of integration, $\Delta^d x_t \sim I(0)$. In other words, if by differencing[2] a time series d times, the resulting series is stationary, then the process is considered integrated of order d.

Stationarity implies the following properties (Stock et al., 2012, 387):

$$\forall h \in \mathbb{Z} : \begin{cases} \mathrm{E}[x_t] = \mathrm{E}[x_{t+h}] = \mu < \infty \\ \mathrm{Var}(x_t) = \mathrm{Var}(x_{t+h}) = \sigma^2 < \infty \\ \mathrm{Cov}(x_t, x_s) = \mathrm{Cov}(x_{t+h}, x_{s+h}) = \gamma_k < \infty, \quad k = |t-s| \end{cases}$$

The order of integration is a fundamental property, because if a time series has an order $d > 0$—i.e., it is non-stationary—and the necessary differences are not applied, many of the properties of the models can be altered. In the specific case of a VAR model like the one we intend to develop, the lack of stationarity can lead to a non-standard distribution (for example, functionals of Brownian motions) of the estimators, and by extension, to the invalidity of traditional inference methods. This could lead us to overestimate the significance of certain test statistics, thus capturing spurious relationships without true causal content.

Anticipating the procedures we will carry out in the next chapter, it turns out that the Bayesian consistency properties of the posterior may be called into question if, despite the lack of stationarity, the likelihood function assumed in the model assumes it. Finally, if we try to analyze the impulse response functions (IRF) of a system that is not stable, these might be poorly defined or not converge.

In order to test for the presence or absence of integration in the variables of our six datasets, we will resort to three different statistical tests that, by testing whether the time series exhibit or not a unit root dynamics or $I(1)$, will allow us to affirm or deny the presence of stationarity in our data. These tests—technical details of which can be consulted in Annex V.10—are the Dickey-Fuller GLS (DF-GLS), the Phillips-Perron (PP), and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS), and their results at 95% confidence are summarized in Table III.3.

According to the results collected in Table III.3, it is observed that, in each and every one of the six databases used, there is at least one variable that, despite having been previously transformed, does not pass all stationarity tests, which suggests that it has an order of integration $d \geq 1$. Before drawing a definitive conclusion or applying additional modifications to the series, we have considered it pertinent to verify whether this lack of stationarity is an intrinsic property of the variables or if, on the contrary, it is an artifact derived from the temporal segmentation of the samples. To do so, we have re-estimated the same integration tests for each of the three time series used (overnight interest rate, inflation rate, and output gap), this time using the complete

[2]Recall that differencing is nothing more than transforming a time series by subtracting from each value in period t its value in the previous period $t-1$: $\Delta x_t = x_t - x_{t-1}$.

Table III.3: Results of stationarity tests

Period and region	Variable	Dickey-Fuller GLS	Phillips-Perron	KPSS
EU pre-COVID	Overnight interest rate	No	No	No
	Inflation rate	Yes	Yes	Yes
	Output gap	No	No	No
EU COVID	Overnight interest rate	No	No	No
	Inflation rate	No	Yes	No
	Output gap	Yes	No	No
EU post-COVID	Overnight interest rate	Yes	No	Yes
	Inflation rate	No	Yes	Yes
	Output gap	No	No	No
USA pre-COVID	Overnight interest rate	No	No	No
	Inflation rate	Yes	Yes	Yes
	Output gap	No	No	Yes
USA COVID	Overnight interest rate	No	No	No
	Inflation rate	Yes	Yes	Yes
	Output gap	Yes	No	No
USA post-COVID	Overnight interest rate	No	No	No
	Inflation rate	Yes	Yes	Yes
	Output gap	Yes	Yes	Yes

Note: It is indicated whether there is sufficient statistical evidence to assert stationarity with 95% confidence.

series without distinguishing between subperiods. The results of this exercise are presented in Table III.4.

After having carried out the global integration tests and paying special attention to the results provided by the DF-GLS and Phillips-Perron tests, it is observed that, except in the case of the variables associated with short-term interest rates, both the inflation rate and the output gap show behavior compatible with stationarity over the complete time interval of the analysis. This result suggests that the apparent lack of stationarity observed in the subperiod estimates would not be attributable to the nature of the series themselves, but to the artificial splits imposed by the structure of the study. In other words, fragmenting the series according to different time phases may have limited our ability to detect their true stochastic dynamics. Thus, although this exercise does not fully guarantee that all desired statistical properties are preserved in the VAR model estimation, the results obtained offer a reasonable basis to consider that, at least in relation to inflation and the output gap, we are not committing any specification error in assuming their stationarity.

Table III.4: Results of stationarity tests by variable and region

Region	Variable	Dickey-Fuller GLS	Phillips-Perron	KPSS
EU-27	Overnight interest rate (EONIA)	No	Yes	No
	Overnight interest rate (€STR)	No	No	No
	Inflation rate	Yes	Yes	No
	Output gap	Yes	Yes	Yes
USA	Overnight interest rate (Fed Funds)	No	No	No
	Inflation rate	Yes	Yes	No
	Output gap	Yes	Yes	Yes

Note: It is indicated whether there is sufficient statistical evidence to assert stationarity with 95% confidence.

III.3.2 Final decision

Collecting the set of results obtained so far—which offer mixed conclusions regarding the convenience of operating with the variables in their current state (without applying additional transformations)—the need to make a definitive decision on the pertinence of imposing stationarity through new transformations becomes clear. Weighing the advantages and disadvantages associated with further modifying our databases, we choose not to alter them further, and therefore, to keep them as they appear in Table III.2.

There are four main arguments that support our decision to maintain the variables as they resulted from the transformations section, despite the existence of non-stationarities in some of them:

1. The fact that, in some combinations of economy and period, the same variable appears as stationary in some cases and non-stationary in others, means that the use of additional transformations—such as differencing—severely compromises the comparability of the models. If, guided by the results of the DF-GLS test, we difference the US interest rate in pre-COVID but not in post-COVID, we would obtain in the first case the rate of change of the interest rate and, in the second, its level. This would make it difficult to establish substantial comparisons and relationships, which are essential for our economic analysis. While one could propose the systematic differencing of all variables to avoid this problem, this strategy would imply losing valuable information in series that do not require it, and moreover, would expose the estimation to the problems associated with overdifferencing.

2. The initial transformations applied to the series had as their main objective to make them analogous to the variables used in the log-linear version of the NK model. In this context, imposing stationarity through additional transformations would prevent us from establishing sign relationships—crucial for the process of identifying structural shocks—from

the theoretical framework. Given that this framework operates with specific transformations, modifying them freely would compromise the ability to correctly identify the perturbations of interest.

3. From a theoretical point of view, the consensus of the economics profession, based on empirical evidence and theory, tends to consider stationary by nature the transformed variables we are working with. Despite the empirical difficulties in justifying stationarity during the COVID period, theory allows us to overcome this obstacle. For example, according to Jordi Galí (2015, 20-21), the stabilizing policy of central banks aimed at avoiding deviations from the natural interest rate ρ justifies the assumption of a stochastically stationary nominal interest rate. Extrapolating this logic to the rest of the endogenous variables—for which other theoretical arguments can be put forward—we can defend the stationary nature of the set of time series and, thus, the maintenance of the applied transformations.

4. Finally, and although this does not apply homogeneously to all time series—especially those of overnight interest rates—the integration tests show that, in general, the presumed lack of stationarity is not due to the intrinsic nature of the series, but to the fact that they have been divided into subperiods to adapt to the objectives of the study. This, while not offering an absolute guarantee against the problems derived from estimation with locally non-stationary series, reinforces confidence in the statistical properties of the global estimation.

The combination of these four considerations, grounded in both empirical results and economic theory, leads us to leave the variables unchanged. We trust that the arguments presented are solid and that this decision will allow us to preserve the good properties of the estimation of the six VARs.

IV MODEL DEVELOPMENT

IV.1 Estimating the reduced-form VAR with Bayesian methods

IV.1.1 Algebraic structure of the VAR model

The basic structure of a VAR model with n endogenous variables and p lags consists of a vector regression in which the current value of each variable is explained as a linear combination of past values of all variables in the system. Formally, a VAR(p) can be expressed as:[1]

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + \epsilon_t \tag{IV.1}$$

where:

- $y_t = (y_{1,t}, y_{2,t}, \ldots, y_{n,t})'$ is an $n \times 1$ column vector containing the values of the n endogenous variables in period t;
- $A_1, A_2, \ldots, A_p$ are $n \times n$ matrices of coefficients that capture the impact of past values of the variables on the current value;
- $\epsilon_t = (\epsilon_{1,t}, \epsilon_{2,t}, \ldots, \epsilon_{n,t})'$ is a vector of errors or structural shocks of the model, representing the part not explained by the autoregressive dynamics.

For analytical convenience, it is commonly assumed that the error terms follow a multivariate Normal distribution with zero mean and variance-covariance matrix Σ:

$$\epsilon_t \sim \mathcal{N}(0, \Sigma)$$

[1]The entire development of this section is heavily inspired by the technical guide of the Matlab toolbox used for the automated estimation of the models, namely The BEAR toolbox (Bayesian Estimation, Analysis and Regression toolbox) of the European Central Bank (ECB). More specifically, this first section on Bayesian estimation of the model coefficients is based on pages 16–25 and 35–40 of Dieppe, Legrand, and Roye (2016).

In accordance with the characteristics of our empirical study, the VAR model we will use is a reduced-form VAR with $n = 3$ endogenous variables and $p = 3$ lags. Thus, the vector form of the model is expressed as:

$$y_t = \begin{pmatrix} \tilde{y}_t \\ \pi_t \\ i_t \end{pmatrix} = A_1 y_{t-1} + A_2 y_{t-2} + A_3 y_{t-3} + \epsilon_t$$

Following the development carried out in Annex V.11, in order to represent the model in a more compact and convenient form for econometric estimation, we can rewrite it in the following matrix form and then vectorize it as follows:

$$Y = XB + \mathcal{E} \Longleftrightarrow y = \bar{X}\beta + \epsilon \quad \text{where} \quad \epsilon \sim N(0, \bar{\Sigma}) \tag{IV.2}$$

IV.1.2 Estimation using an independent normal-Wishart prior

If we were to opt for a frequentist approach, once we had the vector structure of the VAR model, the task would simply consist of estimating the parameters via Ordinary Least Squares (OLS) and then proceeding to identify the structural shocks. However, this approach assumes that there is a "true" or "real" value of the parameters. Instead, we will start from the assumption that there is a certain indeterminacy in the values of these parameters, which is captured via a probability distribution function.

This assumption, which constitutes the essence of the Bayesian approach, allows combining the information coming from the data—the likelihood function $f(y|\theta)$—with a certain *a priori* structure on the distribution of the parameters—the prior distribution function $\pi(\theta)$—thus obtaining the posterior distribution of the parameters given the observations y:

$$\pi(\theta|y) \propto f(y|\theta)\pi(\theta) \tag{IV.3}$$

The assumptions we incorporate to define the prior distribution of the parameters are the following:

- The true values of the model parameters θ, specifically the model coefficients β and the error variance-covariance matrix Σ, are unknown.

- The coefficients β follow a multivariate normal distribution with mean β_0 and variance-covariance matrix Ω_0: $\beta \sim N(\beta_0, \Omega_0)$. Thus, their prior distribution function is:

$$\pi(\beta) \propto \exp\left[-\frac{1}{2}(\beta - \beta_0)' \, \Omega_0^{-1} (\beta - \beta_0)\right]$$

- The matrix Σ is distributed according to an inverse Wishart with scale matrix S_0 and α_0 degrees of freedom: $\Sigma \sim \mathcal{W}^{-1}(S_0, \alpha_0)$. Therefore, its prior density function is:

$$\pi(\Sigma) \propto |\Sigma|^{-(\alpha_0+n+1)/2} \exp\left[-\frac{1}{2}\operatorname{tr}\left\{\Sigma^{-1}S_0\right\}\right]$$

Once the prior distributions are defined, the likelihood function of the data must be specified, also assuming normality:

$$\begin{aligned} f(y|\beta,\Sigma) \propto |\Sigma|^{-T/2} \exp\left[-\frac{1}{2}(\beta-\hat{\beta})'\left(\Sigma \otimes (X'X)^{-1}\right)^{-1}(\beta-\hat{\beta})\right] \\ \times \exp\left[-\frac{1}{2}\operatorname{tr}\left\{\Sigma^{-1}(Y-X\hat{\beta})'(Y-X\hat{\beta})\right\}\right] \end{aligned}$$

Combining—according to equation (IV.3)—the likelihood function with the prior distributions, and omitting the intermediate steps of rearrangement and transformation, we obtain the joint posterior distribution:

$$\begin{aligned} \pi(\beta,\Sigma \mid y) \propto |\Sigma|^{-(T+\alpha_0+n+1)/2} &\exp\left[-\frac{1}{2}(\beta-\bar{\beta})'\bar{\Omega}^{-1}(\beta-\bar{\beta})\right] \\ \times &\exp\left[-\frac{1}{2}\hat{\beta}'\left(\Sigma^{-1}\otimes X'X\right)\hat{\beta}+\beta_0'\Omega_0^{-1}\beta_0-\hat{\beta}'\bar{\Omega}^{-1}\hat{\beta}\right] \\ \times &\exp\left[-\frac{1}{2}\operatorname{tr}\left\{\Sigma^{-1}\left[(Y-XB)'(Y-XB)+S_0\right]\right\}\right] \end{aligned}$$

where:

$$\bar{\Omega} = \left[\Omega_0^{-1}+\Sigma^{-1}\otimes X'X\right]^{-1}, \quad \bar{\beta} = \bar{\Omega}\left[\Omega_0^{-1}\beta_0+\left(\Sigma^{-1}\otimes X'\right)y\right]$$

and $\hat{\beta}$ and $\hat{B}$ are the OLS estimates of the regression coefficients.

From this general expression, we can derive the conditional distributions of the two sets of parameters:

$$\pi(\beta|\Sigma,y) \sim N(\bar{\beta},\bar{\Omega}) \quad \text{and} \quad \pi(\Sigma|\beta,y) \sim \mathcal{W}^{-1}(\hat{S},\hat{\alpha}) \tag{IV.4}$$

where:

$$\hat{S} = (Y-XB)'(Y-XB)+S_0, \quad \hat{\alpha} = T+\alpha_0$$

Once these conditional posterior distributions are established, we can proceed to estimate the parameters using a Gibbs sampling algorithm. This algorithm generates, over n iterations, random samples of the parameters β and Σ according to their conditional distributions. After the iterations are completed, the median of the samples is used as a point estimator of the parameters.[2]

[2]The median is used instead of the mean because, although both lie within the credibility interval, the mean is

IV.2 Constructing the structural VAR with sign restrictions

IV.2.1 Algebraic structure of the SVAR model

Although, as we have seen earlier, we already have a robust Bayesian estimation of the central parameters of the reduced-form VAR model—that is, the expectation of the regression coefficients β and the error variance-covariance matrix Σ—these results still do not allow us to identify the impact of different structural shocks on the economic variables.[3]

The problem lies in the structure of the perturbation vector ϵ_t. In general, its variance-covariance matrix is not diagonal, meaning that the shocks it contains are correlated. This mutual dependence implies that the effects of each individual shock cannot be interpreted autonomously, as it is not possible to isolate their specific contribution: a shock ϵ_t^i can be influenced by, or be the cause of, other shocks ϵ_t^j, ϵ_t^k, etc. Therefore, the analysis of their effects does not have a clear economic interpretation.[4]

To solve this identification problem, the reduced-form VAR must be reformulated into a structural model (SVAR) by introducing a set of structural matrices D_i. Starting from the original specification:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + A_3 y_{t-3} + \epsilon_t$$

we transform the model into the following SVAR structure:

$$D_0 y_t = D_1 y_{t-1} + D_2 y_{t-2} + D_3 y_{t-3} + \varepsilon_t \tag{IV.5}$$

From now on, we will define $D \equiv D_0^{-1}$, which allows us to establish a direct link between the components of the structural model and those of the reduced-form model:

$$A_i = D D_i, \quad \epsilon_t = D \varepsilon_t$$

The key property of this structural matrix D is that it «permits to recover structural innovations from the reduced-form VAR residuals» (Dieppe, Legrand, and Roye, 2016, 75):

$$\Sigma = \mathrm{E}[\epsilon_t \epsilon_t'] = \mathrm{E}[D \varepsilon_t \varepsilon_t' D'] = D\, \mathrm{E}[\varepsilon_t \varepsilon_t'] D' = D \Gamma D'$$

In other words, the structural matrix D allows us to establish a linear relationship between the stochastic errors of the reduced-form model, ϵ_t, and the underlying structural shocks, ε_t. Under

more sensitive to extreme values and, therefore, can deviate from the center of the distribution.

[3] As in the previous subsection, this subsection is heavily influenced by the technical guide of the BEAR toolbox, more specifically pages 74–76 and 80–85 of Dieppe, Legrand, and Roye (2016).

[4] I must thank my supervisor Sergi Basco for providing me with the material by Anna Mikusheva (2007) from MIT, as those notes allowed me to understand and clarify the motivation behind the construction of the SVAR models I have just outlined.

the usual assumption that structural shocks—unlike reduced-form model perturbations—are orthonormal, i.e., orthogonal (uncorrelated with each other) and normalized (with unit variance), the error variance-covariance matrix can be expressed in terms of the structural matrix as: $\Sigma = D\Gamma D'$, where Γ is the second-order moment matrix of the structural shocks (in the standard orthonormal case, $\Gamma = I$).

As we advanced in chapter II, the Wold Representation Theorem implies that, under the assumption of covariance stationarity (an assumption we clearly uphold), it is possible to invert any lag polynomial—like that of our reduced-form VAR model—into the form of an infinite-order moving average process, i.e., an MA(∞) (Blanchard and Quah, 1989, 657):

$$y_t = A(L)^{-1}\epsilon_t = \Psi_0\epsilon_t + \Psi_1\epsilon_{t-1} + \Psi_2\epsilon_{t-2} + \dots \tag{IV.6}$$

where $A(L) \equiv I - A_1L - A_2L^2 - \dots - A_pL^p$ is the lag polynomial of the vector of endogenous variables y_t, and the matrices $\Psi_0, \Psi_1, \Psi_2, \dots$ represent the impulse response functions (IRFs) of the reduced-form VAR model. These functions capture the dynamic effect that different shocks (in this case, non-structural) have on the variables of the system. Specifically, the effect of a shock ϵ_t on the variable y_{t+h} at horizon h is given by: $\frac{\partial y_{t+h}}{\partial \epsilon_t} = \Psi_h$.

Transforming this moving average according to the structural conditions of the SVAR model, we can reformulate the previous equation as follows:

$$y_t = A(L)^{-1}\varepsilon_t = \sum_{i=0}^{\infty} \tilde{\Psi}_i\varepsilon_{t-i} = \tilde{\Psi}_0\varepsilon_t + \tilde{\Psi}_1\varepsilon_{t-1} + \tilde{\Psi}_2\varepsilon_{t-2} + \dots \tag{IV.7}$$

where

$$\tilde{\Psi}_0 \equiv D \quad \text{and} \quad \forall i = 1, 2, 3, \dots : \quad \tilde{\Psi}_i \equiv \Psi_i D$$

In short, $\tilde{\Psi}_h = \frac{\partial y_{t+h}}{\partial \varepsilon_t}$ represents the response of the endogenous variables, at horizon h, to a structural shock. Since Γ is a diagonal matrix, these impulse response functions correspond to independent shocks, allowing them to be assigned a well-defined economic interpretation.

IV.2.2 Identification with sign restrictions

The final step in constructing our model consists of designing a structural matrix D that effectively implements the sign restrictions established in chapter II. Unlike other types of restrictions, such as short-run restrictions or long-run restrictions, which admit—at least in theory—a direct and unique identification by solving a system of equations, sign restrictions require an algorithmic procedure. This process involves generating and selecting candidate structural matrices, retaining exclusively those that satisfy the pre-established sign restrictions.

However, before describing the steps of the algorithmic procedure in detail, it is pertinent to introduce a series of matrices and functions that will appear recurrently throughout the process and will be essential in the identification phase. Given an SVAR model as presented in equation IV.5, and since we are interested in having a matrix that collects the different structural IRFs corresponding to the periods subject to restrictions, we will define a function $f(D, D_1, D_2, \ldots, D_H)$ such that, if the sign restrictions are to be implemented over a horizon $h = 0, 1, 2, \ldots, H$, then:

$$f(D, D_1, D_2, \ldots, D_H) = \begin{pmatrix} \tilde{\Psi}_0 \\ \tilde{\Psi}_1 \\ \vdots \\ \tilde{\Psi}_H \end{pmatrix}$$

In order to check whether a given collection of structural matrices $D, D_1, \ldots, D_H$ satisfies, or not, the desired structural restrictions, it is necessary to describe a set S_j of selection matrices. These matrices, defined for $j = 1, 2, \ldots, n$ structural shocks (with $n = 3$ in our case), have as many columns as rows in $f(D, D_1, D_2, \ldots, D_H)$, and as many rows as the number of sign restrictions imposed on shock j.

All elements of the selection matrix are zero, except those entries representing the sign restrictions: these take the value -1 in the case of a negative restriction and 1 in the case of a positive restriction. Thus, in order to check whether a collection of structural matrices complies with a given identification scheme, i.e., whether they satisfy the restrictions imposed for shock j, we must validate that:

$$S_j \times f_j(D, D_1, D_2, \ldots, D_H) > 0$$

where $f_j(D, D_1, D_2, \ldots, D_H)$ represents the jth column of the matrix $f(D, D_1, D_2, \ldots, D_H)$.

Now that we have an idea of the functioning and role of these two functions, we can proceed to describe the operation of the Gibbs sampling algorithm:

1. We define the three selection matrices S_j containing the sign restrictions associated with the three structural shocks (supply, demand, and monetary policy), assuming a duration of one quarter for each shock.

2. We establish the number of successful iterations of the algorithm. Indeed, by convention and for practical criteria, while a total number of iterations It is fixed, a specific number of initial *burn iterations* Bu are also specified, which, although eventually discarded, serve to condition and orient the selection of matrices. In this way, and adopting the default values provided by the *BEAR toolbox*, the number of successful iterations of our Gibbs algorithm will be: $It - Bu = 2.000 - 1.000 = 1.000$.

3. At each iteration n, the values of the parameters of the reduced-form VAR model, $B_{(n)}$ and $\Sigma_{(n)}$, are retrieved from their posterior distributions, using the median as the estima-

tor.

4. Once we have the central parameters of the reduced-form VAR model, and through the transformation to MA(∞) allowed by the Wold Representation Theorem, we can obtain the impulse response functions (IRF) associated with the perturbation term for each time horizon. Formally, at each iteration n we retrieve $\Psi_0^{(n)}, \Psi_1^{(n)}, \Psi_2^{(n)}, \ldots$.

5. Before obtaining our definitive structural matrix for iteration n, we must start by defining a preliminary structural matrix $h(\Sigma)$, where $h(\cdot)$ can be any continuous and differentiable function of positive symmetric matrices, such that: $h(\Sigma) \times h(\Sigma)' = \Sigma$. This is because, as we saw in the last subsection, one of the conditions of the structural matrix is that, from it—and also from Γ—we must be able to recover the variance-covariance matrix of the reduced-form VAR model. But, with Γ being an identity matrix due to orthonormality requirements, it is pertinent that the Cartesian product of the preliminary matrix and its transpose equals Σ. Following the consensus and due to its good properties, the function $h(\cdot)$ chosen to perform this preliminary transformation will be the Cholesky decomposition—or factorization.

   Once we have this transformation, we can apply it without any problem to the variance-covariance matrix and, from it, obtain preliminary structural IRFs:

$$\bar{\Psi}_i^{(n)} = \Psi_i^{(n)} h(\Sigma_{(n)})$$

   This transformation allows us to obtain IRFs that, although they do not yet satisfy the orthogonality condition, represent a previous version of the structural responses that will be useful for their subsequent validation.

   Next, the stacked matrix of preliminary IRFs is constructed via the function $\bar{f}(D, D_1, \ldots, D_H)$, which gathers all the response functions generated up to horizon H (in our case, $H = 3$), thus forming a compact representation of the dynamic behavior of the system for the various shocks:

$$\begin{pmatrix} \bar{\Psi}_0^{(n)} \\ \bar{\Psi}_1^{(n)} \\ \vdots \\ \bar{\Psi}_3^{(n)} \end{pmatrix}$$

6. Nevertheless, it turns out that these preliminary IRFs we have just elaborated do not come from a correct distribution, since we have not imposed the orthogonality condition on the preliminary structural matrix. In order to correct this deficiency and obtain the definitive structural matrices, we will have to define an additional matrix Q such that, being generated from random values drawn from a uniform distribution, it is orthogonal.

The product of the preliminary structural matrix and this new orthogonal matrix will allow us to obtain the final structural matrix of the nth iteration:

$$D = h(\Sigma)Q$$

For practical purposes, this matrix Q is obtained by randomly generating the elements of an auxiliary matrix X using a standard normal distribution. Applying a QR decomposition, or factorization, to X, we obtain matrix Q. Once we have this new matrix, we can move from provisional to definitive IRFs:

$$\tilde{\Psi}_i^{(n)} = \Psi_i^{(n)} D = \Psi_i^{(n)} h(\Sigma_{(n)}) Q = \bar{\Psi}_i^{(n)} Q$$

7. We create the stacked matrix of definitive structural IRFs:

$$f(D, D_1, \ldots, D_3) = \begin{pmatrix} \tilde{\Psi}_0^{(n)} \\ \tilde{\Psi}_1^{(n)} \\ \vdots \\ \tilde{\Psi}_3^{(n)} \end{pmatrix} = \begin{pmatrix} \bar{\Psi}_0^{(n)} \\ \bar{\Psi}_1^{(n)} \\ \vdots \\ \bar{\Psi}_3^{(n)} \end{pmatrix} Q = \bar{f}\,(D, D_1, \ldots, D_3) \times Q$$

8. We check whether, for $j = 1, 2, 3$ shocks, the stacked IRF matrix satisfies the sign restrictions; i.e., whether $S_j \times f(D, D_1, \ldots, D_3) > 0$. If the restrictions are satisfied, then we keep Q for the next iteration. Otherwise, if these restrictions are violated, Q will be discarded and steps 3–8 will be repeated until a valid one is obtained.

9. This procedure is repeated until $In - Bu$ valid iterations have been obtained.

The result of this algorithmic process, i.e., the 1,000 structural matrices $D^{(n)}$ that satisfy the sign restrictions, are aggregated together—often summarized using some statistic such as the mean, median, or credibility intervals—with the aim of generating the main analytical tools of the SVAR models, specifically the shock plots, the impulse response functions to structural shocks (IRFs), and the historical decompositions (HDs).

IV.3 Correction via *dummy initial observations*

Before proceeding with the presentation of the results, it is necessary to explain a small modification introduced due to the effects of non-stationarity of some series (especially overnight interest rates) on the identification of structural shocks.

As mentioned earlier, stationarity is characterized, among other things, by the fact that the mathematical expectation of the variables is constant over time. When this condition is not met, i.e., when there is a significant correlation between the time moment and the expected value of the series, we speak of a time dependence dynamic. In this case, successive observations can be largely described from their past values. Formally, if the expected value of a variable at time t is x_t and there is a relationship of the form

$$\mathrm{E}[x_t] \approx \mathrm{E}[x_{t-1}] + \tau$$

where τ is a systematic trend, then a substantial part of the variation of the series can be explained simply by its historical trajectory. Reiterating this scheme backward in time, we can reach the initial instant, so that the current value of the variable can be largely described from its initial observation or *initial observation*. This situation drastically reduces the model's ability to attribute observed variability to genuine structural shocks.

This problem has clearly manifested itself when estimating the models for the COVID and post-COVID scenarios. Interest rate series with unit root dynamics meant that most of their variation was absorbed by the initial values, rather than being attributed to structural shocks, producing implausible results—for example, suggesting that monetary policy in the US was expansionary at the end of the pandemic. Given this risk to the robustness of the estimates, despite not affecting the overall goodness of fit, it was decided to introduce a specific modification in the prior of these last four models.

Fortunately, the *BEAR toolbox* itself has a mechanism called *dummy initial observation* that mitigates the effects of non-stationarity on the identification of structural shocks, especially when series exhibit unit roots.

In essence, this procedure consists of adding a single fictitious observation for each endogenous variable. This observation is constructed from the sample mean of each series in the period prior to the sample, scaled by the hyperprior parameter λ_7. Formally, the matrices are defined:

$$Y_o = \begin{pmatrix} \frac{\bar{y}_1}{\lambda_7} & \cdots & \frac{\bar{y}_n}{\lambda_7} \end{pmatrix},$$

and

$$X_o = \begin{pmatrix} \mathbf{1}_{1\times p} \otimes Y_o & \frac{\bar{x}}{\lambda_7} \end{pmatrix},$$

where $\bar{x} = (\bar{x}_1, \ldots, \bar{x}_m)$ is the vector of means of the exogenous variables over the p initial conditions, and $\otimes$ denotes the Kronecker product. In this scheme, Y_o has dimension $1 \times n$, X_o has dimension $1 \times (np + m)$, and a single fictitious period ($T_o = 1$) is generated.

To illustrate, consider a VAR with two endogenous variables and two lags ($n = 2,\ p = 2$) and one exogenous variable ($m = 1$). The system with the fictitious observation can be written, compactly, as:

$$\begin{pmatrix} \frac{\bar{y}_1}{\lambda_7} & \frac{\bar{y}_2}{\lambda_7} \end{pmatrix} = \begin{pmatrix} \frac{\bar{y}_1}{\lambda_7} & \frac{\bar{y}_2}{\lambda_7} & \frac{\bar{y}_1}{\lambda_7} & \frac{\bar{y}_2}{\lambda_7} & \frac{\bar{x}_1}{\lambda_7} \end{pmatrix} \begin{pmatrix} a_{11}^1 & a_{21}^1 \\ a_{12}^1 & a_{22}^1 \\ a_{11}^2 & a_{21}^2 \\ a_{12}^2 & a_{22}^2 \\ c_{11} & c_{21} \end{pmatrix} + (\varepsilon_{1,1} \; \varepsilon_{1,2}).$$

Developing, for example, the first equation:

$$\frac{\bar{y}_1}{\lambda_7} = \frac{\bar{y}_1}{\lambda_7} a_{11}^1 + \frac{\bar{y}_2}{\lambda_7} a_{12}^1 + \frac{\bar{y}_1}{\lambda_7} a_{11}^2 + \frac{\bar{y}_2}{\lambda_7} a_{12}^2 + \frac{\bar{x}_1}{\lambda_7} c_{11} + \varepsilon_{1,1},$$

which, multiplying by λ_7, is rewritten as:

$$\bar{y}_1 - \bar{y}_1 a_{11}^1 - \bar{y}_2 a_{12}^1 - \bar{y}_1 a_{11}^2 - \bar{y}_2 a_{12}^2 - \bar{x}_1 c_{11} = \lambda_7 \, \varepsilon_{1,1}.$$

Taking expectations yields the "no-change" condition:

$$\bar{y}_1 = \bar{y}_1 a_{11}^1 + \bar{y}_2 a_{12}^1 + \bar{y}_1 a_{11}^2 + \bar{y}_2 a_{12}^2 + \bar{x}_1 c_{11},$$

and, for the variance,

$$\operatorname{Var}\big(\bar{y}_1 - \bar{y}_1 a_{11}^1 - \bar{y}_2 a_{12}^1 - \bar{y}_1 a_{11}^2 - \bar{y}_2 a_{12}^2 - \bar{x}_1 c_{11}\big) = (\lambda_7)^2 \sigma_1^2.$$

Thus, λ_7 acts as a shrinkage parameter of the prior: when $\lambda_7 \to \infty$, the prior is diffuse; when $\lambda_7 \to 0$, the "no-change" restriction becomes effective. In this limit, either (i) all variables settle at their unconditional mean, which induces stationarity at the system level despite the presence of individual unit roots (implying cointegration), or (ii) the collective dynamics are governed by an unspecified number of unit roots sharing a common stochastic trend.

Operationally, the integration of the *dummy initial observation* into the BVAR estimation is done by stacking these fictitious rows onto the original data (and, if applicable, onto other dummies such as the sum-of-coefficients dummy):

$$Y^* = \begin{pmatrix} Y \\ Y_d \\ Y_o \end{pmatrix}, \quad X^* = \begin{pmatrix} X \\ X_d \\ X_o \end{pmatrix}, \quad T^* = T + T_d + T_o,$$

and applying the same posterior distributions as in the base case, substituting (Y, X, T) with (Y^*, X^*, T^*). This procedure is compatible with the rest of the priors (such as our independent normal-Wishart) and can be used together with other dummies or in isolation, as appropriate for the empirical specification.

Thanks to the use of this correcting *dummy*, we have obtained estimates that, although they involve a reduction in the log-likelihood value and, in some cases, a slight deterioration in the goodness of fit for certain variables, have allowed for a much more satisfactory identification of the shocks, thus facilitating a more realistic and precise analysis.

V RESULTS

Using the tools provided by the European Central Bank's *toolbox*, the modeling methods described above—Bayesian estimation with an independent normal-Wishart prior and identification via sign restrictions through the Gibbs algorithm—have been implemented in the six databases considered. This application has resulted in six econometric models that, predictably, will allow a rigorous description of the effects of monetary policy over the analyzed period.

V.1 Preliminary evaluation

Before proceeding with the presentation of the obtained results and their corresponding analysis, it is necessary to pause to evaluate the overall performance of the estimated models. This preliminary evaluation has, first, the objective of determining whether the models have been able to satisfactorily describe the recent evolution of the North American and European economies, and, by extension, whether they constitute a sufficiently realistic *proxy* of their behavior so that the derived results are representative and applicable to the underlying economies. If any model captures the dynamics of a given economic variable in a deficient manner, the results obtained from that model regarding the impact of monetary policy on that variable would likely be unreliable and scarcely realistic.

Second, this evaluation also aims to examine the plausibility of the identification procedure used. This procedure consists of assigning each of the three stochastic perturbation terms of the model a specific label, according to their relationship with the exogenous variables (for example, the label "monetary shocks" has been attributed to those perturbations that cause opposite movements between interest rates and the inflation rate). In this context, one of the outputs generated by the models are the time series corresponding to the estimated structural shocks. Comparing these series with actual economic events and news will allow us to assess to what extent the perturbations identified as "monetary policy shocks" effectively reflect the economic reality that was intended to be modeled.

V.1.1 Goodness of fit

Beginning with the analysis of the goodness of fit of the models, the main metrics of the vector regressions—the coefficient of determination R^2, the log-likelihood, and the deviance information criterion (DIC)—have been summarized in Table V.1.

Table V.1: Summary of metrics per model and variable

Model	R^2 Interest rate	R^2 Inflation	R^2 Output gap	Log-likelihood	DIC
EU pre-COVID	0.970	-0.189	0.823	265.58	-1257.79
EU COVID	0.960	0.098	0.624	-	-413.24
EU post-COVID	0.942	-0.308	-0.092	-	-352.40
USA pre-COVID	0.990	0.104	0.922	279.29	-1325.03
USA COVID	0.978	0.159	0.664	-	-467.42
USA post-COVID	0.934	0.011	0.040	-	-439.29

One of the first issues that stands out in the analysis of the summarized metrics is the quality of the estimation that all models provide for the interest rate and the output gap. In all the subperiods considered, the estimation of the overnight interest rate offers an almost perfect fit to the observed data, with values of the coefficient of determination R^2 never falling below 0.90.

Regarding the output gap, although the fits are not as precise, the results remain satisfactory. During the period following the COVID-19 pandemic, the R^2 values fall within the interval 0.80–0.95, while for the pandemic period, they are between 0.64 and 0.67.

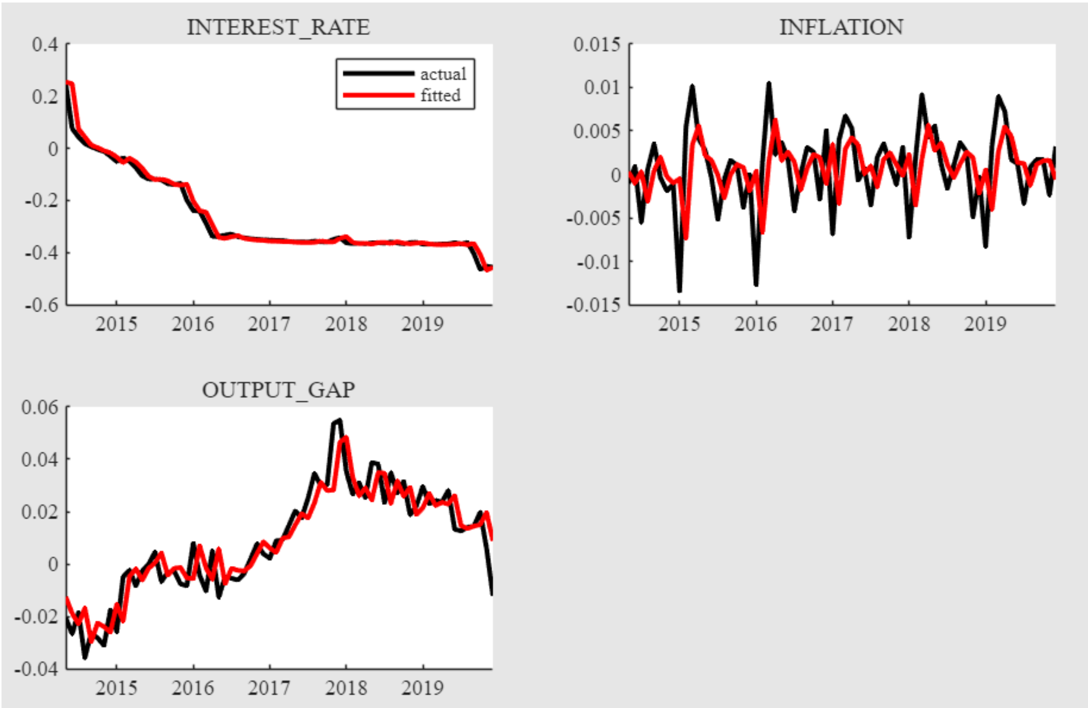
However, it should be noted that there is a significant drop in the quality of the fit associated with the output gap during the post-COVID period, with R^2 values that, in none of the cases, exceed the threshold of 0.10.

Regarding the other two criteria considered—the log-likelihood and the deviance information criterion (DIC)—it should be noted that, although they are useful tools for comparison between nested models (in the case of the log-likelihood) or non-nested models (in the case of the DIC), their informative capacity is limited in the absence of alternative models. In this context, these criteria provide little relevant information for the autonomous evaluation of the goodness of the estimated models.

At the same time, it is worth highlighting the difficulties of the model in accurately estimating the values of the inflation rate. The low values of the coefficient of determination—in some cases even negative—which at no point exceed the threshold of 0.2, suggest that the regression presents important limitations in explaining the dynamics of prices solely from combinations of past values of the vector of endogenous variables.

A visual analysis of the *Matlab* outputs (Figure V.1)—which provide a comparison between the estimated and observed values—allows us to identify two main problems in the estimation of inflation: (1) a systematic tendency to present a slight time lag, of approximately one month, between the estimated and real values, and (2) an underestimation of the amplitude of the oscillations of the series, with local maxima and minima less pronounced in the estimation than in the real data.

Figure V.1: Comparison of estimated and actual values for EU pre-COVID



Source: Own elaboration.
Note: The red series represents the model estimates (*fitted*), and the black series represents the actual values (*actual*).

Despite these inconveniences, it should be noted that, as illustrated in the graph, the general trajectory of the estimated series aligns reasonably faithfully with that of the observed data. Moreover, the model is able to adequately capture the timing of the main inflection points, although it does not always reflect their magnitude exactly.

Thus, while acknowledging that the fit of the inflation series is less satisfactory than that of other variables, we can confidently state that the model offers an overall adequate estimation of the set of economic series, which allows us to extract valid conclusions for the analyzed economies.

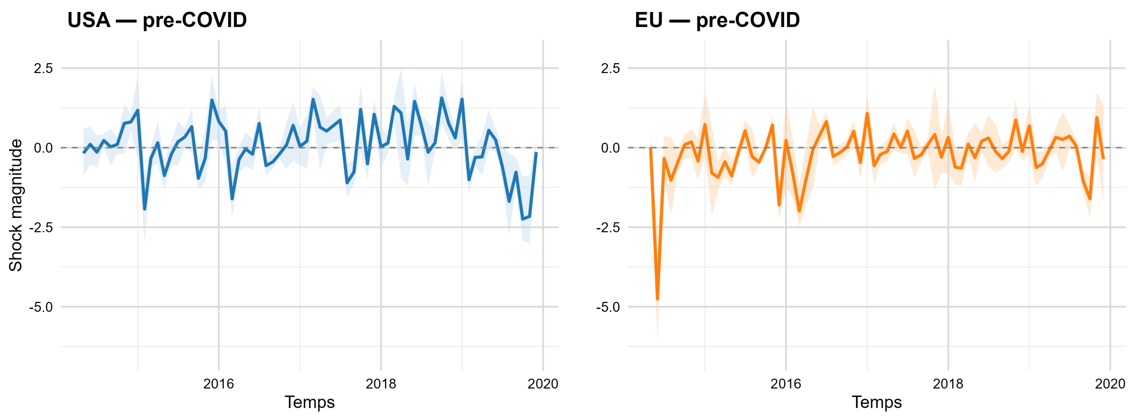
V.1.2 Plausibility of the shocks

As already mentioned at the beginning of this section, the last part of the preliminary analysis consists of evaluating the degree of realism of the obtained estimates of structural shocks of a monetary nature. This exercise aims to examine the general shape and fluctuations of the estimated shock time series, in order to determine whether they seem to coherently reflect the monetary policy events that occurred before, during, and after the crisis caused by COVID-19.

Before assessing the plausibility of the shocks, it is convenient to clarify the functioning of the models and the set of phenomena we have grouped under the label "monetary policy shocks". In the identification process we have associated these shocks with perturbations that generate simultaneous and opposite sign movements in the interest rate and inflation rate variables; this methodological decision prevents, by definition, discriminating between the different sources that can produce those movements. Thus, although the initial objective of the work was to analyze the effect of reductions in official interest rates (conventional monetary policy), the identification structure used does not allow separating these effects from those of other non-conventional instruments—for example, massive asset purchase operations (*quantitative easing*) or other direct interventions in bond markets. Consequently, the results must be interpreted taking into account that the monetary policy we capture in the model is a potential combination of both sources; the minimalist identification approach does not disaggregate the specific contribution of interest rate reductions relative to that of supply operations, and therefore, both possibilities must be considered when explaining the empirical patterns obtained.

Having said that, it is worth recalling that, according to the identification scheme used, positive values of the monetary policy shock actually correspond to contractionary perturbations, such as increases in official interest rates, *quantitative tightening* (QT) measures, or other news that anticipate a reduction in financing conditions.

Figure V.2: Estimated monetary shocks for the pre-COVID period



Source: Own elaboration.

Regarding the European Union during the period prior to the pandemic (Figure V.2), it is observed that between mid-2014 and the end of 2017 monetary shocks predominantly have a negative sign, that is, an expansionary profile. In coherence with the economic context of the moment, the graph registers a notable monetary expansion in mid-2014, which coincides with the start of *quantitative easing* (QE) policies on the European continent. More specifically, this peak seems to correspond with the announcement of the *Targeted Long-Term Refinancing Operations* (TLTROs), made by the European Central Bank on June 5, 2014. From that moment on, although the magnitude of subsequent shocks decreases, a clear expansionary orientation of monetary policy is maintained.

Another notable episode occurs between the end of 2015 and the beginning of 2016, coinciding with an increase in the monthly purchases of the QE program, which translates into two pronounced drops in the estimated values of monetary shocks.

Subsequently, during the phase of fiscal and monetary normalization that characterizes the period between the end of 2017 and mid-2019, a clear moderation in monetary stimulus is observed. The values of the shocks tend to be more positive (contractionary), in line with the objectives of containing inflationary pressures and strengthening the euro, especially after the episodes of weakness derived from the Great Recession and the sovereign debt crisis.

Finally, towards the end of 2019, a new uptick in expansionary perturbations is identified, coinciding with the reactivation of quantitative easing measures designed to address the uncertainty generated by international trade tensions.

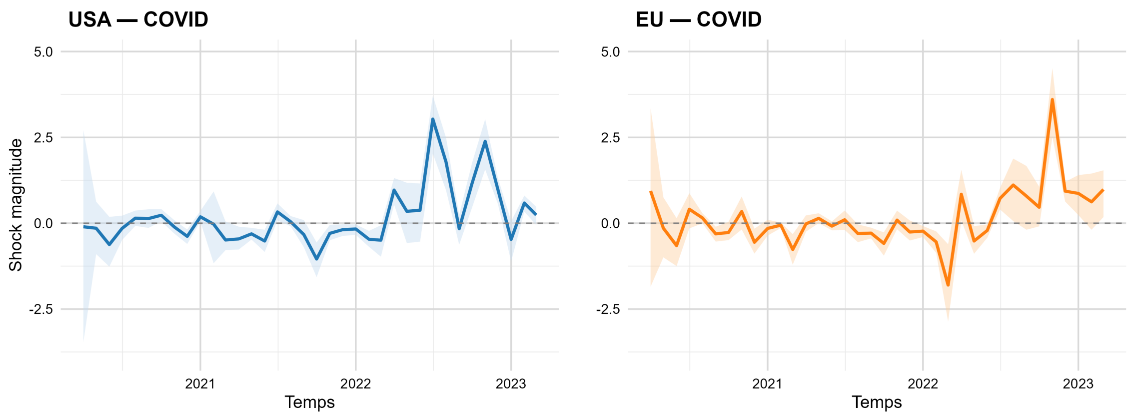
In the United States, during this same period, a significantly different economic reality is observed. Although the scale of the graphs could be misleading, it should be noted that the monetary policy shocks experienced by the North American economy were, in general, less intense than those recorded in Europe.

The first notable element is that, between the end of 2014 and the beginning of 2015, the Federal Reserve ended the third monetary stimulus program, known as *quantitative easing* 3 (QE3), which coincides with the last expansionary shocks observed at the beginning of 2015.

From that moment on, and especially from the end of 2015—when the first increase in official interest rates since the beginning of the financial crisis occurred (from 0.25% to 0.50%)—a sustained trend towards contractionary monetary policy shocks is evident, culminating at the end of 2018. During this period, the combination of the end of the QE program, the start of QT, and a cycle of gradual interest rate hikes—which reached 2.50% in December 2018—constitute the distinctive features of the Federal Reserve's monetary policy.

However, this trend clearly reversed at the beginning of 2019, in response to growing threats of economic slowdown and the achievement of a level of inflation considered stable. This new expansionary stage translated into three reductions in official interest rates throughout the year—to around 1.5%—, the end of QT, and the reactivation of stimulus measures through a new QE program.

Figure V.3: Estimated monetary shocks for the COVID period



Source: Own elaboration.

Regarding the period between the start of the COVID-19 pandemic (Figure V.3) in Western economies and the end of exceptional policies to address it, a very similar evolution of monetary policy shocks is observed in both Europe and the United States.

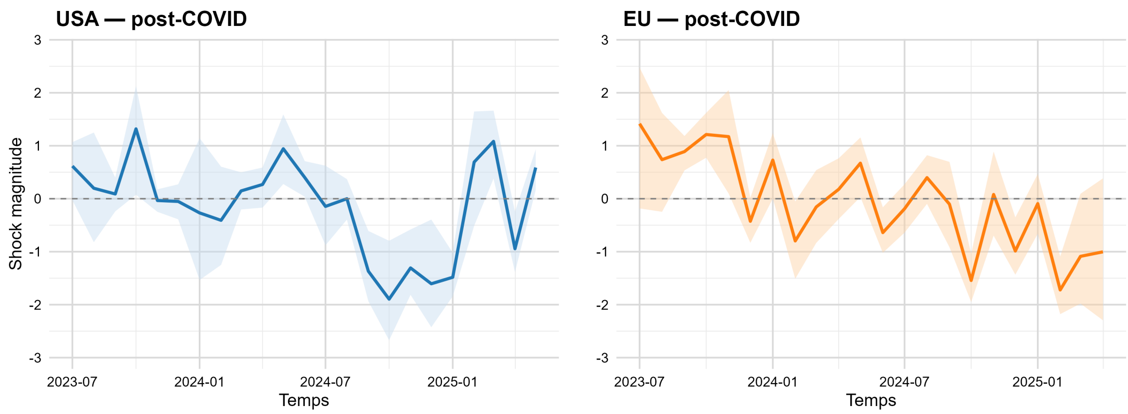
In general terms, until the beginning of 2022, the role of monetary policy in macroeconomic development was relatively modest. Although it was foreseeable to identify some local minima coinciding with the rapid reductions in official interest rates following the economic complications derived from the pandemic and mobility restrictions, the graphs do not reflect any significant monetary perturbation, and the estimated shocks remain close to the abscissa axis. This lack of intensity is probably explained by the fact that overnight interest rates were already, at that time, at values very close to zero. In a context of strong mobility restrictions, high uncertainty, and a substantial increase in household savings, interest rate reductions tended to have a very limited effect on aggregate income.

However, towards the end of 2021 and the beginning of 2022, some relative minima are observed—probably associated with the last quantitative easing measures adopted by both the Federal Reserve and the European Central Bank—before the direction of monetary policy changed decisively. From that moment on, monetary authorities initiated a markedly contractionary trajectory. The massive capital injections and fiscal stimuli deployed during the pandemic, combined with still lax monetary policy, significantly boosted aggregate demand. This, however, could not be satisfied by an aggregate supply strongly limited by the disruption of supply chains, the increase in unemployment, and the presence of bottlenecks in various industries. The asymmetry between supply and demand led to generalized inflationary tensions, which translated into a sustained increase in the general price level.

To address this inflationary escalation and the associated social discontent, monetary authorities opted to abruptly end their expansionary policies. In the United States, this shift materialized in the reintroduction of *quantitative tightening* and an extraordinary increase in official interest rates—unprecedented in recent times—which reached 4% by the end of 2022 and exceeded 5% by mid-2023. In the European Union, the main refinancing rate (currently considered the ECB's benchmark rate) increased to 2.50% in December 2022, and continued to rise to reach 3.75% in May 2023.

Overall, it can be stated that the estimated time series of structural shocks present a high concordance with the actual events observed during this period.

Figure V.4: Estimated monetary shocks for the post-COVID period



Source: Own elaboration.

Again, and despite certain minor differences, it should be noted that the estimated series of monetary policy shocks in the United States and the European Union present, in general terms, a similar evolution during the post-COVID period, between April 2023 and the present.

Through the corresponding graphs, a decreasing trend in the shock time series can be appreciated, indicating a shift from a predominantly restrictive monetary policy towards a more expansionary orientation. This reading is consistent with the events observed during the analyzed period. Until approximately mid-2024, monetary authorities continued to focus on combating inflationary tensions, although they did so mainly through the application of measures such as QT and other policies of a similar nature, rather than through new interest rate hikes, which remained relatively stable since mid-2023.

This period of restrictions concluded around the second quarter of 2024, when the major Western economies managed to stabilize inflation rates close to the targets of their respective central banks (around 2%). In this new scenario, a progressive de-escalation of contractionary monetary policies became possible, which explains the proximity to neutral values (around zero) that the estimated series present during the first half of 2024.

However, the stagnation—and risk of recession—that affected some of the major economies of the euro area, such as Germany, as well as growing international trade tensions, motivated a change in the orientation of monetary policy from the third quarter of 2024. This new direction was characterized by a flexibilization of financing conditions with the aim of stimulating economic activity. This flexibilization manifested itself through reductions in benchmark interest rates and the definitive end of QT programs.

Despite public pressures exerted by President Donald Trump on the Federal Reserve to reduce interest rates—with the aim of facilitating the refinancing of American public debt—the results obtained by the models indicate that the economic area that has maintained a more sustained expansionary profile in recent months has actually been the European Union. A possible explanation for this divergence lies in the international context: the trade and financial policies promoted by the United States caused a notable depreciation of the dollar against the euro, which forced the Federal Reserve to maintain relatively high interest rates to continue attracting international capital and reinforce the demand for dollars, in order to ensure its position in the global financial system.

V.2 Historical decomposition

In order to analyze the contribution of each shock to the evolution of the three macroeconomic series of interest, historical decomposition (HD) graphs have been elaborated for each subperiod and for each variable. These graphs show the evolution of the different macroeconomic variables, as well as the specific contribution of each type of shock to explaining the observed deviations from the steady state. This representation, articulated through stacked bar charts, allows not only comparing the relative importance of the monetary factor relative to the other two main macroeconomic factors (supply and demand), but also obtaining a view of its evolution over time and the effects exerted on the different analyzed variables. Consequently, it constitutes one of the fundamental pillars of the comparative analysis developed in this chapter.

V.2.1 Overnight interest rate - results

The evolution of overnight interest rates shows differentiated dynamics between the European Union and the United States over the analyzed periods, although with some common traits in specific stages.

During the pre-COVID period, the EU experienced a sustained reduction in interest rates, which fell by approximately 0.8 percentage points, reaching levels even more negative than those immediately following the Great Recession. The historical decomposition graph indicates that the bulk of this decline is attributable to monetary policy, with an average contribution of 44.76% of the total variation. In the United States, on the other hand, no decreasing trend is observed, but rather the opposite: short-term interest rates increased steadily until early 2019 (by almost 2.5 percentage points), then began a descent that left them 1.5 percentage points above the initial level. During the first years of the period, monetary policy did not play as determining a role as in Europe; until early 2017, monetary shocks explained on average only 9.90% of the variation. However, between 2017 and 2019, their contribution in the US gained relevance, reaching an average of 19.05%.

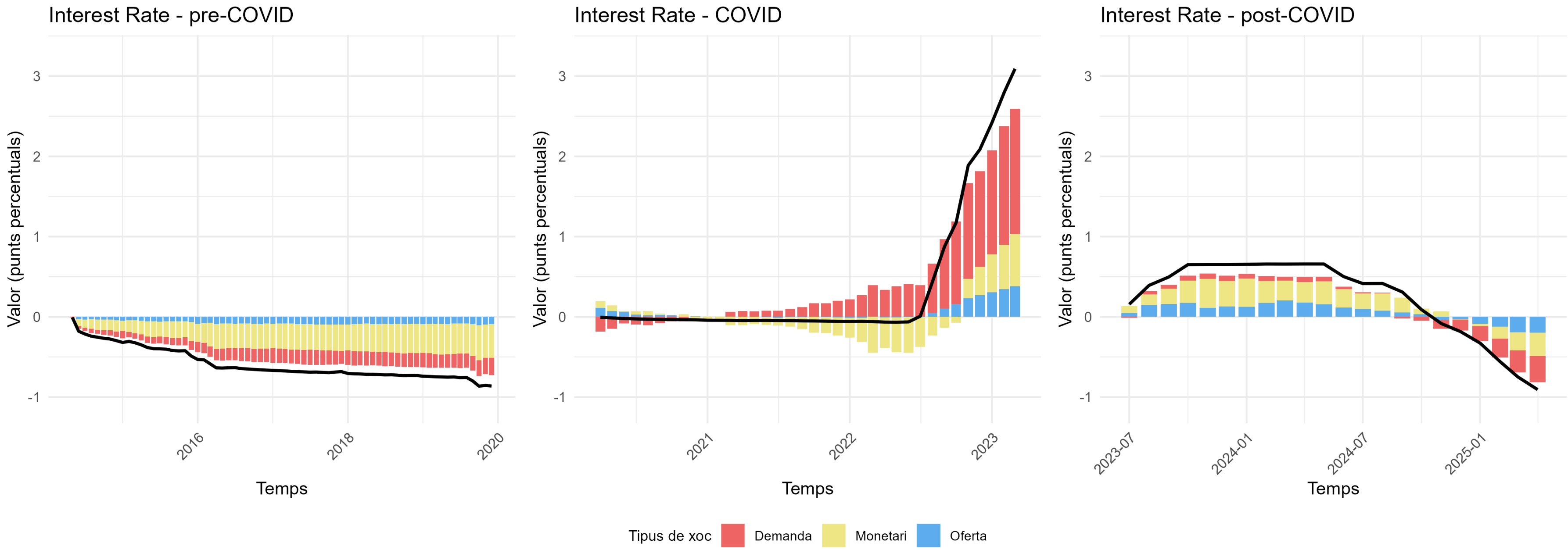
With the arrival of the pandemic, both economies showed similar patterns. In the euro area, interest rates, already at very low levels, did not experience major changes, and the contribution of monetary policy was relatively modest. However, during the first half of 2022, when demand pressures were pushing interest rates upward, expansionary monetary policy managed to fully offset these pressures. Although the overnight rate varied little in percentage terms, the downward contribution of monetary shocks was approximately 609.11%. Towards the end of the pandemic, and in combination with supply and demand shocks, restrictive monetary policy contributed modestly to the sharp rise in overnight interest rates (with an average of 13.98%), which increased by up to 3 percentage points.

In the United States, a similar dynamic was observed, almost identical to that of the European Union. During the first months of the pandemic, monetary policy, instead of offsetting demand shocks, acted by counteracting supply shocks, keeping interest rates practically immobile, with an average negative contribution of 111.49%. Subsequently, in the context of the increase in interest rates at the end of the pandemic—which meant an increase of up to 4 percentage points—the contribution of monetary policy shocks was 15.96%.

In the post-COVID period, and following the inertia of the pandemic stage, monetary policy in the EU acquired a central role in explaining interest rate increases until the end of 2023, with an average contribution close to 45%. This phase involved a cumulative increase of more than 0.5 percentage points relative to the initial values. By mid-2024, the general trend reversed and interest rates began to fall, so that by the end of 2025 they were almost 1 percentage point below the post-pandemic starting level. In this decline, monetary policy played a relevant but balanced role, explaining on average about 20% of the deviation from the steady state.

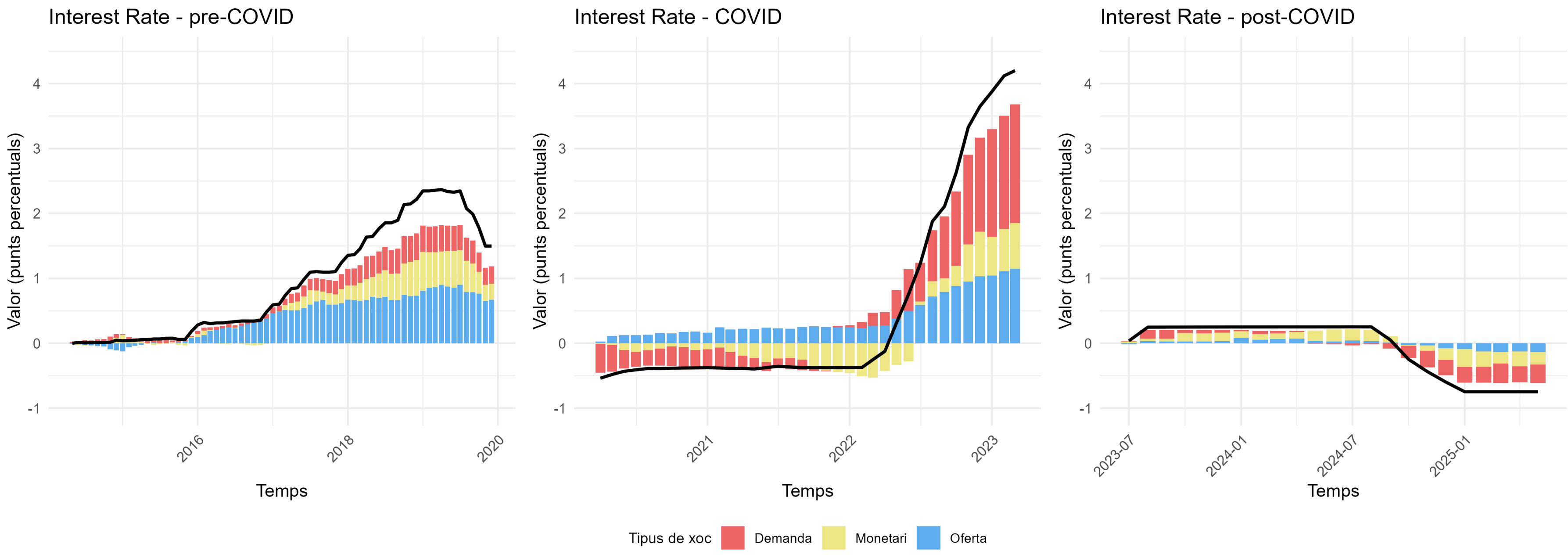
In the United States, the dynamic was similar: an initial phase marked by an abrupt rise in interest rates—of eminently monetary origin, with a contribution of shocks of 43.7%—, followed by a period of reductions where the incidence of the three types of shocks (monetary, supply, and demand) was more balanced. However, compared to Europe, monetary policy had a greater weight in the recent reductions in interest rates, with an average contribution of 30%, reinforc-

Figure V.5: Historical decomposition of the overnight interest rate in the EU



Source: Own elaboration.

Figure V.6: Historical decomposition of the overnight interest rate in the USA



Source: Own elaboration.

ing the role of the Federal Reserve as a central actor in shaping the cost of credit in the North American economy.

V.2.2 Overnight interest rate - interpretation

In general, the most plausible explanation for the evolution of European interest rates at the beginning of the pandemic can be attributed mainly to the expansionary monetary policy inherited from the financial crisis and the sovereign debt crisis. This inertia conditioned the European Central Bank's immediate capacity to act, as it was already starting from extraordinarily low interest rates (a scenario close to a *liquidity trap*) and, therefore, with very limited room for maneuver.

Regarding the United States, the increase in rates recorded in the pre-COVID period seems to be due to a lesser extent to monetary policy, and much more to the real conditions of the economy: on the one hand, the demand for financing by firms; on the other, the supply of resources derived from savings, i.e., supply and demand shocks. However, the growing role that monetary shocks adopted at the end of 2019 is plausibly explained by the deliberate policy of the Federal Reserve, aimed at lowering interest rates to stimulate the economy in the face of threats derived from the trade war with China.

After the impact of the pandemic, central banks hastened to lower official interest rates and relax their credit policy to assist an economic fabric severely weakened. This explains, in part, the modest downward influence that monetary policy had on the interest rate during the first half of the COVID phase. However, the existence of such low interest rates on both sides of the Atlantic meant that, no matter how much effort monetary authorities made, overnight rates resisted falling much further. This illustrates a paradigmatic case of what the literature calls the *effective lower bound*, which limits the capacity of conventional expansionary policies.

Towards the end of the pandemic, in the European Union, the increase in demand—partly driven by public spending—, combined with the deliberate action of monetary authorities to contain inflationary pressures, certainly explains the rapid rise in interest rates. The practically identical evolution observed in the United States likely responds to similar dynamics, with monetary policy tightening in the face of the urgent need to curb the price escalation.

The credit restrictions applied by both the ECB and the Federal Reserve, in the form of quantitative tightening and increases in official rates, kept overnight rates high until mid-2024. From that moment on, the progressive relaxation of monetary policy—which adopted an expansionary bias at the beginning of 2025—, combined with contractionary supply and demand shocks derived from the trade war and uncertainty in international markets, exerted downward pressure on the cost of financing.

V.2.3 *Inflation rate - results*

The expansionary monetary policies that characterized the years prior to the pandemic in the European Union, while generating a positive impulse on economic activity, also contributed to an increase in prices in the form of higher inflation rates. More specifically, the average monthly inflation rate of the subperiod was 0.0923%, which, annualized, implies an interannual inflation of 1.11%. It should be noted that the average contribution of monetary policy in this context is difficult to compute due to the values very close to zero presented by the time series, which acts as a denominator in the computation and generates artificially high values. However, direct observation of the graphs indicates that, although monetary policy did not play a determining role in aggregate income, it exerted a notable positive influence on prices and the inflation rate.

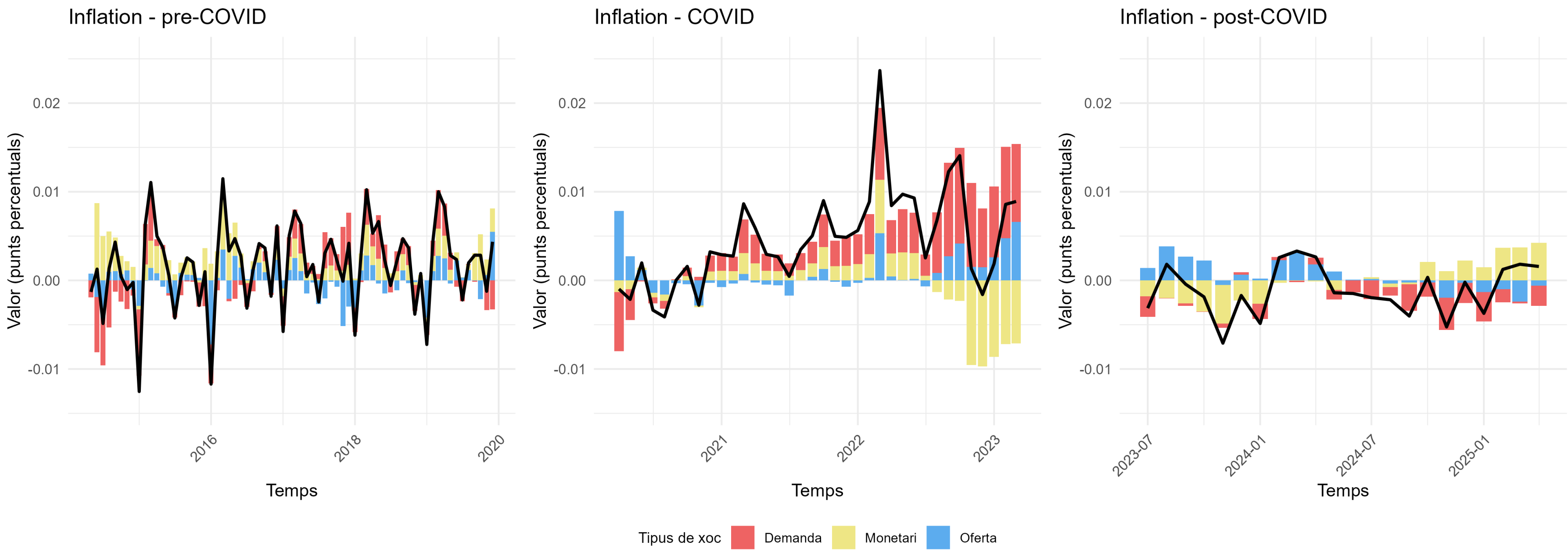
In the United States, the situation presents notable differences. Although, as in the EU, the average monthly inflation rate (0.13%) and the interannual rate (1.61%) are positive and modest, the bulk of the price increase seems to originate mainly in supply factors and not in monetary shocks. In several periods, the contribution of monetary shocks seems contrary to the increase in the general price level. This dynamic changed drastically in the last quarter of 2019, when monetary policy explained up to 143.66% of the total variation in the inflation rate.

During the first half of the pandemic period, monthly inflation rates, although they only reached negative values punctually just after the outbreak of the crisis, experienced a notable reduction compared to previous values. Specifically, during the year 2020, the average monthly inflation rate was 0.016% in the EU and 0.109% in the US, with corresponding interannual rates of 0.20% and 1.31%. It is observed that European inflation fell to much lower levels than North American inflation. In both cases, the contribution of monetary policy to these rates was very modest compared to the other shocks, with values so close to zero that the calculation of average contributions becomes trivially high.

In the second half of the pandemic, the situation changed radically, with abnormally high inflation rates in both regions. In the US, between 2021 and the first quarter of 2023, the average monthly rate was 0.39% and the interannual rate 4.83%, while in the EU, in the same period, the average monthly rate was 0.61% and the interannual rate 7.64%. Initially, monetary shocks were not the main *driver* of inflation (average contribution of 35% in the EU and 26% in the US), but from the second half of 2022, their participation became more significant and of opposite sign to the general direction of inflation. In this subperiod, the average contribution of monetary shocks was -85.44% in the EU and -70% in the US.

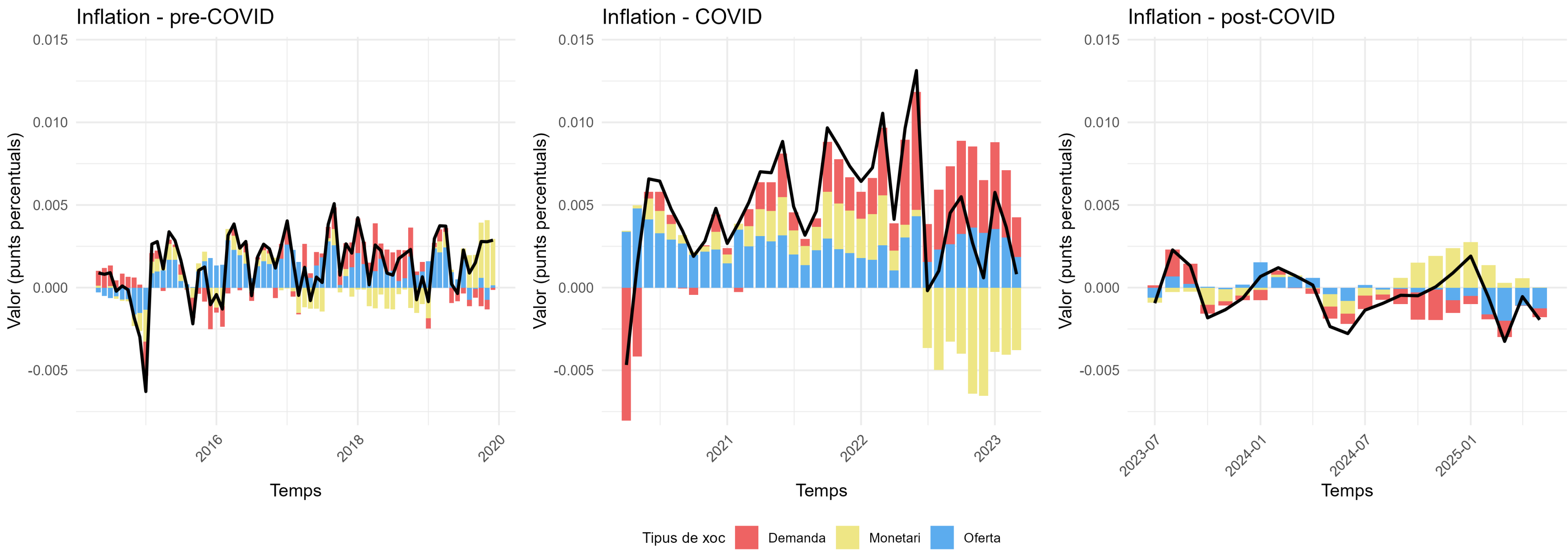
At the end of the pandemic and during the first phase of the post-COVID period, demand and supply pressures continued to push inflation to high levels. Monetary policy shocks exerted pressure of opposite sign which, although not fully compensating for the effects of the other shocks at the beginning, managed to mitigate inflation rates by mid-2023. Thus, the average

Figure V.7: Historical decomposition of the inflation rate in the EU



Source: Own elaboration.

Figure V.8: Historical decomposition of the inflation rate in the USA



Source: Own elaboration.

monthly inflation rate in the EU between July 2023 and January 2024 was 0.084% and in the US 0.26%. Although disinflation was more intense in Europe, both regions experienced a moderation in price increases.

In the middle of the post-COVID period, a normalization of the monthly inflation rate is observed in both economies and a very modest contribution of monetary policy. However, between the end of 2024 and 2025, monetary policy shocks exert upward pressure on inflation against the direction of supply and demand shocks. The main difference is that, while in the US the impact ceases in mid-2025 and allows inflation to decline to moderate levels, in the EU it persists, so that high monthly rates are maintained. During the last three months studied, monetary shocks contribute on average to fueling European inflation by 257.59%, while in the US this contribution is antagonistic to inflation and much smaller, at -38.38%.

V.2.4 Inflation rate - interpretation

The rigidities of aggregate supply, still present after the Great Recession, caused that the credit facilities provided by the ECB translated more into inflationary pressures than into a proportional increase in production. In contrast, the United States, with a more sound and restructured productive fabric, showed a greater capacity to grow without the need for strong monetary expansions, which was reflected in more moderate inflation rates than those in the euro area. However, the start of the trade war at the end of the decade pushed both economies, especially the North American one, to resort to expansionary monetary policies that, in a context of limited productive capacity, fueled inflation again.

The price dynamics associated with the pandemic period seem relatively similar in both regions. Despite not falling into deflationary territory, there was a strong contraction in inflation rates due to the decline in real activity. Although the fall in aggregate output tended to put upward pressure on prices, this pressure was offset by the reduction in household income and consumption, keeping inflation contained. This balance broke at the beginning of 2021, when inflation rates rebounded on both sides of the Atlantic. In this initial phase, monetary policy played a relatively modest role, as high levels of uncertainty and the increase in hoarding largely neutralized the effect of liquidity injections by central banks.[1] Thus, the inflation of the middle and

[1] As Professor Jesús Huerta de Soto aptly points out (2021, 26-30), in non-catastrophic pandemics such as COVID-19—unlike devastating pandemics such as the bubonic plague—the increase in uncertainty, combined with the expectation of a relatively near overcoming of the crisis, leads economic agents to increase their cash balances and allocate a larger proportion of their income to hoarding. This increase in hoarding, as already exposed by Wicksell (1962, 52), is nothing more than an increase in monetary demand, i.e., a reduction in the velocity of circulation of money. In this framework, and according to the quantity equation, $M \cdot V = P \cdot Q$, the decrease in V derived from the willingness to increase cash balances means that the increases in M induced by monetary authorities are totally or partially compensated by the increase in monetary demand. Consequently, both the real effects (on Q) and the nominal effects (on P) of monetary shocks are strongly limited.

However, Huerta de Soto warns that, even though in extraordinary circumstances such as those of the pandemic monetary injections may be deprived of immediate effects, their remnant can end up translating into real distortions end of the pandemic is fundamentally explained by the strong expansion of aggregate demand, fueled by government fiscal stimuli, which exceeded the response capacity of supply.

Faced with these tensions, monetary authorities adopted a restrictive stance to reverse the upward trend. This change of direction, especially in the US, seems to arrive excessively late (*too late*), since, before the start of the restrictions, the Fed's monetary policy was at least an important factor in fueling price increases. Regardless of this delay, between the end of 2022 and the beginning of 2023, inflationary pressures still exceeded the contractionary effects of central banks, but by mid-2023 monetary policy managed to impose itself and progressively reduce inflation.

In the post-COVID period, the normalization of economic conditions returned monetary policy to a central role in the evolution of inflation. Its influence was more pronounced in the euro area than in the United States. In the first years after the pandemic, Europe deployed a broad set of restrictive measures to contain price pressures, while the North American economy, more flexible and dynamic, absorbed demand tensions more easily without needing to resort as intensively to monetary policy.

However, by mid-2024, the emergence of recession or stagnation prospects in many Western economies prompted a change of direction in monetary policy, again oriented towards stimulus. Although the real effects were limited, this new orientation caused an inflationary rebound in both the United States and the European Union. The US, immersed in the trade war, activated stimulus programs with more pronounced increases in the price level, followed by the euro area a few months later. The strong monetary expansion of the Federal Reserve caused a depreciation of the dollar, forcing the moderation of expansionary policies by mid-2025 to protect the hegemonic role of the North American currency in international trade.

V.2.5 Output gap - results

Beginning with the European Union, it should be noted that, within the framework of the progressive but modest increase in the output gap observed after the Great Recession, monetary policy played a determining role in this post-crisis phase. From 2015 onwards—and discarding observations that, due to presenting values very close to zero, could distort the calculations—the average contribution of monetary policy to the widening of the output gap before COVID-19 was 94.94%, with an almost 100% contribution between 2015 and 2017 and a more balanced contribution between 2017 and 2019. These figures show that monetary policy acted as a key element in sustaining the recovery and mitigating the prolonged repercussions of the crisis. However, these percentages must be contextualized: during this period the deviation of the output gap from its steady-state level was very modest; therefore, despite representing a high

and increases in prices once the economic and social situation normalizes. This is precisely what happened in the later years of the COVID period.

percentage of the variations, the absolute impact of monetary policy on output was relatively contained.

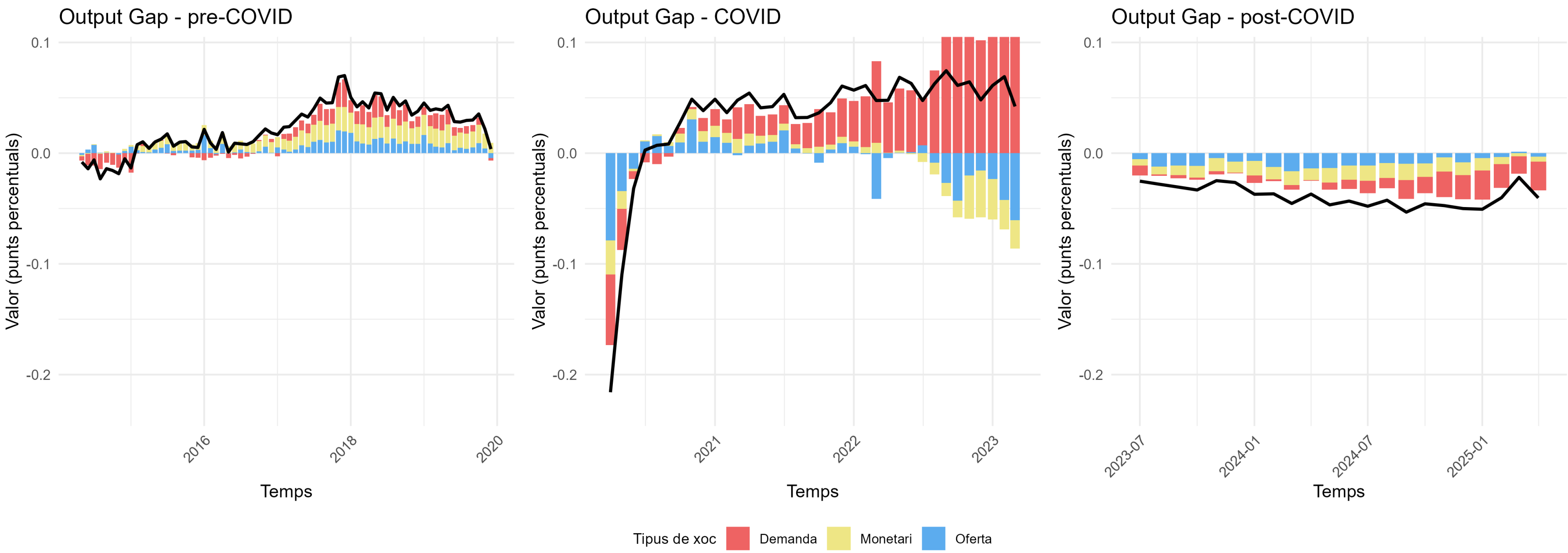
In the United States, during the first half of the period, monetary policy exerted a much more limited influence on the output gap than in the Old Continent; in fact, this initial stage was characterized by a fall in the output gap explained mainly by supply factors. In contrast, from 2018 onwards—coinciding with a gradual normalization of the macroeconomic context—monetary policy acquired a more relevant role in the evolution of North American GDP, with contributions progressively more similar to those observed in Europe. Reproducing the same calculation procedure as in the EU case, the average contribution of monetary shocks to the variation of the output gap was 19.65% of the total, suggesting that the North American economy had a greater capacity to absorb shocks without relying as much on the action of monetary policy.

During the first half of the pandemic stage, an analogous behavior of monetary shocks relative to the direction of the output gap is observed. Despite the violent fall associated with the outbreak of the pandemic, in neither of the two economies did monetary shocks play a relevant or significant role. However, moving to the second half of the period, it can be observed that, while in the United States monetary policy becomes practically neutral and does not seem to have relevant effects on output, the impact of monetary policy on the output gap of the European Union was notably recessionary from mid-2022 onwards. For the entire COVID period, in the European Union, the average contribution was only 5.42%, while in the United States it was 4.42%.

In Europe, the markedly contractionary nature of monetary policy during the post-pandemic period stands out. After the pandemic, monetary policy shocks presented an average contribution of 27% to the variation of the output gap, mostly negative, since the output gap was below its steady-state level, thus contributing to the reduction of the income level. A certain skepticism must be maintained regarding these results, as it would be implausible to assume that all post-pandemic periods presented a negative output gap, especially at the end of the period.

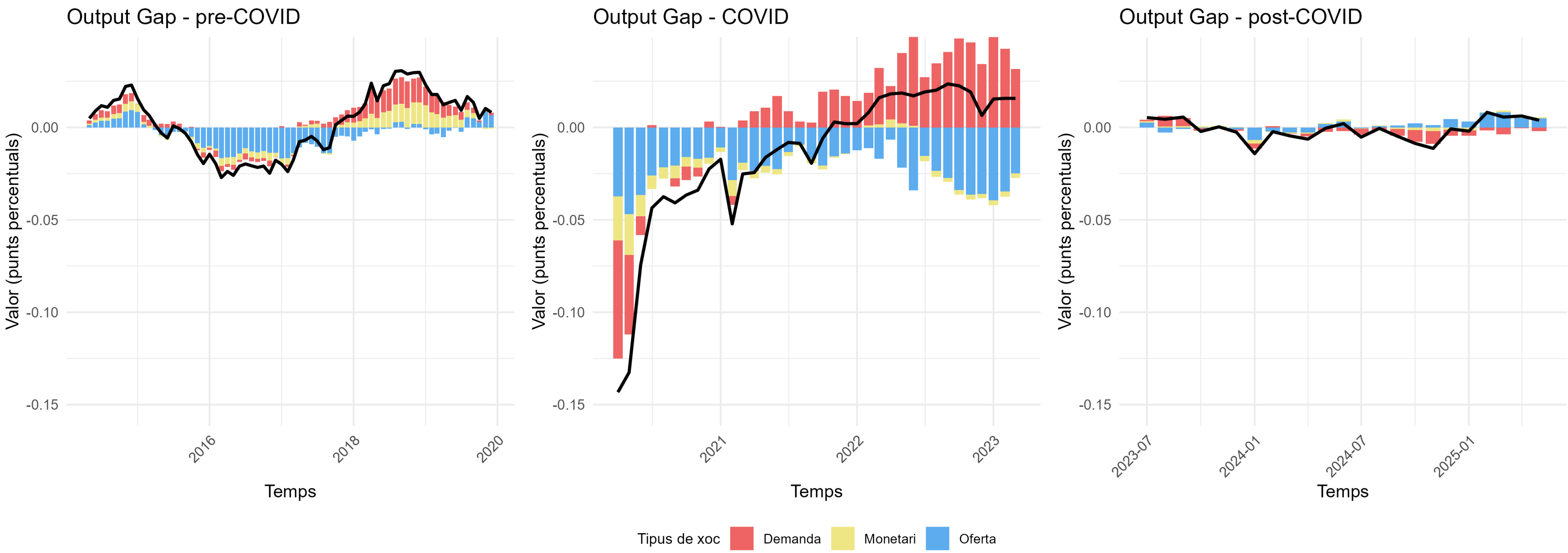
In the United States, the post-pandemic panorama is similar to that before the pandemic. The average contribution of monetary policy shocks to the variation of the output gap was 18.9% (very similar to the pre-COVID period), with positive values at the beginning of the subperiod and negative at its conclusion. Within the studied sample, both positive values, mainly at the beginning of the subperiod, and negative at the end are observed. Comparing these results with the historical decomposition of the inflation rate, it is suggested that—as in the COVID period—during the post-COVID period the *trade-off* between inflation and output (or employment) of monetary policy was not operating, since the effect on output and prices was not systematically opposite according to the orientation of the policy.

Figure V.9: Historical decomposition of the output gap in the EU



Source: Own elaboration.

Figure V.10: Historical decomposition of the output gap in the USA



Source: Own elaboration.

V.2.6 Output gap - interpretation

In Europe, several factors such as the lack of credibility of southern countries and the legacy of the sovereign debt crisis meant that the downward phase of the Great Recession lasted longer and deepened more than necessary to correct the structural imbalances from the expansionary phase and the real estate bubble. This additional depression, of an eminently financial nature, manifested itself when governments, firms, and families competed to clean up their balance sheets through asset liquidations and refinancing searches. In this context, the expansionary monetary policy of the ECB had a key but modest role in overcoming the deflationary threat that hit the Old Continent (Praet, 2017):[2] (1) the liquidity injection allowed absorbing part of the idle productive capacity derived from the forced depreciation of assets, (2) the purchase of sovereign debt and rescue programs for countries like Greece helped restore market confidence, despite the impact on the international reputation of the euro, and (3) extraordinarily cheap financing facilitated access to credit for all economic agents, albeit with the risk of perpetuating inefficient investments or fostering corporate zombification (Huerta de Soto, 2019). All this explains why monetary policy played a role in preventing GDP from falling further after the Great Recession, although it was unable to foster significant growth rates due to the presence of a liquidity trap.

In contrast, in the United States deviations of output from its natural level resulted scarcely conditioned by the direction of monetary policy. This does not necessarily indicate a lack of effectiveness of the policy (as we will see in the section dedicated to IRFs), but simply a lack of use of monetary instruments to conduct economic policy. Even in a scenario of economic weakness such as the *aftermath* of the Great Recession, the output gap showed little sensitivity to being explained in terms of monetary shocks and, in general, was determined by a combination of supply and demand factors; in fact, it is plausible to identify much of the negative supply shock recorded at the beginning of 2018 with the start of the trade war between China and the United States. As already pointed out, the notable flexibility of internal prices in the North American economy means that the real effectiveness of monetary policy, in the absence of extraordinary circumstances, remains restricted to the very short term: the abundance or scarcity of cash tend to be reflected almost immediately in prices, rather than causing lasting alterations in the real and productive structure of the economy.

During the pandemic, both in the European Union and the United States, the direction of the output gap—including the sharp fall at the beginning of 2020—was hardly altered by monetary policies (Lepetit and Fuentes-Albero, 2022). Faced with the simultaneous contraction of production (supply) and income (demand), the extraordinary measures of central banks had a

[2] In the words of the author: «the evidence for the effectiveness is clear. Our monetary policy has contributed to a major easing of euro area financing conditions and, through this channel, to a more robust and sustained economic recovery.»

limited impact on GDP: despite the abundance of cheap financing, the lack of viable business projects and the increase in hoarding by households neutralized their possible real effects.

It is worth noting, however, the contractionary effects of monetary policy shocks at the end of the post-COVID period in the European Union. This phenomenon—and its contrast with the behavior observed in the United States—is explained by the concept of inflation anchoring. As Bernanke and Blanchard remark (2025, 6–9), when inflation expectations are firmly anchored—i.e., when agents believe that monetary authorities will respond strongly enough to contain inflationary shocks—these shocks can often be cooled without resorting to forceful discretionary policies. On the contrary, if agents anticipate a price increase, they have incentives to bring forward sales and postpone purchases (they perceive that today's goods will be more expensive than tomorrow's), behavior that can additionally fuel the initial inflation and become a *self-fulfilling prophecy*. If, instead, central banks manage to establish widespread expectations that any price increase will be quickly neutralized by their action, agents will maintain their usual behavior and inflation can moderate without extreme contractionary policies. Within this *framework* the difference observed between the United States and the European Union is explained: the promises of the ECB are less credible than those of the Fed and, therefore, to cool the same level of inflation the ECB must assume greater sacrifices in terms of output than the Fed does not have to make.

Moving on to the post-COVID era, and as anticipated by the reflections of Marriner Eccles—in line with the theses of John Maynard Keynes—monetary policy presents a clear asymmetry: it can be ineffective as an expansionary instrument (*pushing on a string*) but very potent as a contractionary tool (*pulling on a string*).[3] This dynamic was illustrated particularly clearly in the European context after the pandemic: while the expansionary efforts of the ECB during the early pandemic had a modest effect on growth, the subsequent restrictive policies contributed to lowering inflation at the cost of significantly slowing economic activity. Thus, numerous productive reactivation projects were thwarted and growth expectations were frustrated by the abrupt increase in financing costs.

However, it should be said that monetary policy did not have the same contribution during the pre-COVID scenario as in the post-COVID one. In light of this, it seems plausible to postulate that part of the loss of real effectiveness of monetary policy during the post-pandemic period is attributable to a combination of factors: high inflationary expectations, lack of business dynamism, and a greater preference for saving in the face of uncertainty. In contrast to the stage after the Great Recession—when the cleaning up of balance sheets of firms, governments, and households allowed cheap credit to favor aggregate income—the post-pandemic scenario was characterized by a severely weakened productive fabric, a citizenry more inclined to hoarding, and an environment where the anticipation of price increases limited the effectiveness of

[3] Statements made by Eccles in the United States *Congress* in 1935.

monetary policy in boosting output.

In the United States, the end of COVID-19 meant a return to real dynamics similar to those of the pre-pandemic period. Its flexible and dynamic economy absorbed monetary shocks more quickly, limiting their real effects and facilitating a faster recovery of economic activity.

V.3 Impulse response functions

Once we have studied the evolution of the time series from the perspective of structural shocks, we can use impulse response functions (IRFs) to analyze, for each combination of variable and economic region, the trajectory described by the impact of a unit monetary shock on a given variable. Having previously explained—chapter IV—the mathematical properties of IRFs, in this section we will use them as analytical tools to unravel the general effects of monetary perturbations on the main macroeconomic variables.

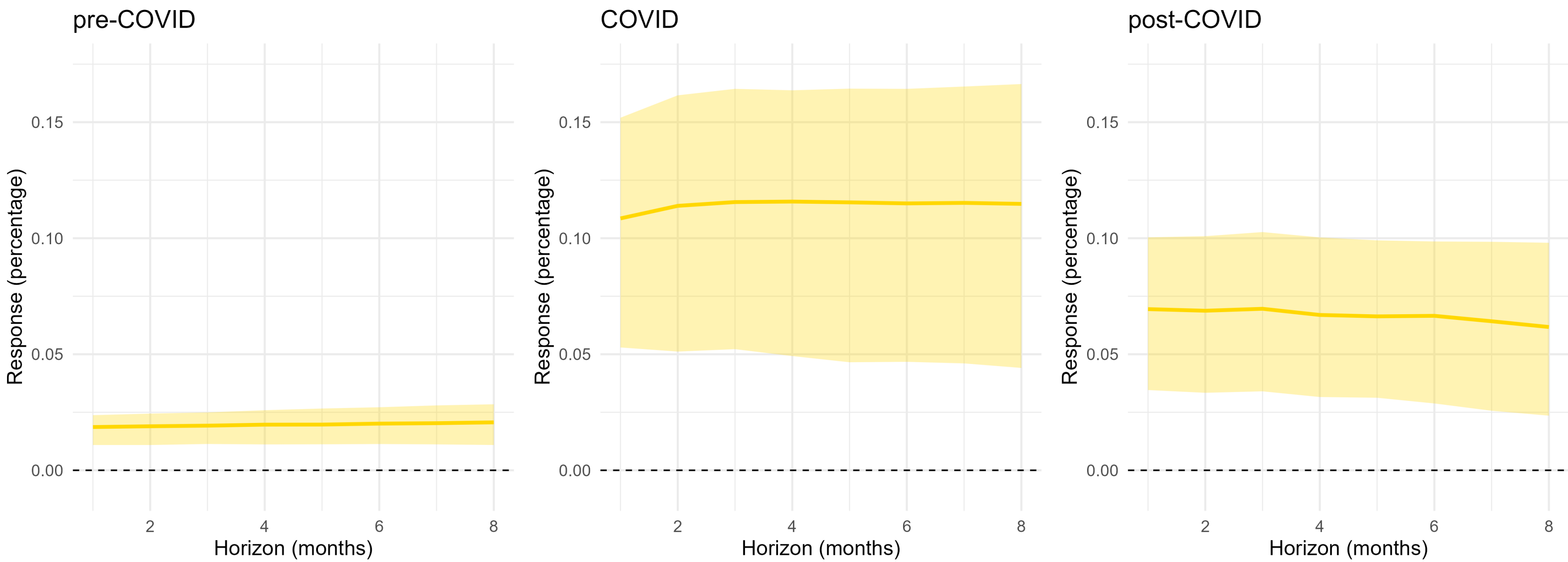
Instead of providing a historical picture of the variables, IRFs place us in a completely isolated scenario, where we simulate, from the parameters of the various models, the impact of a specific shock on a given variable. The resulting graph of this simulation provides information not only about the magnitude and sign of the initial shock, but also about the degree of persistence, the possibility of reversion, and other dynamic characteristics of the propagation of the shock over time. This analytical exercise allows us to delve deeper into dynamics already observed in the historical decompositions and, at the same time, identify patterns difficult to isolate with the graphs studied earlier.

V.3.1 Overnight interest rate - results

As expected, in all the studied subperiods it is observed that the shape of the impulse response functions of the interest rate is very similar. More specifically, we observe IRF graphs characterized by a straight or almost straight line, located at positive values and remaining stable, or at most moderating slightly, over time. This indicates that monetary policy shocks have persistent effects on overnight interest rates and that, due to their magnitude, they generate significant percentage variations. For this reason, the relevant element in this comparative analysis is the *global* magnitude of the impact of monetary shocks on interest rates, rather than the shape of the graph.

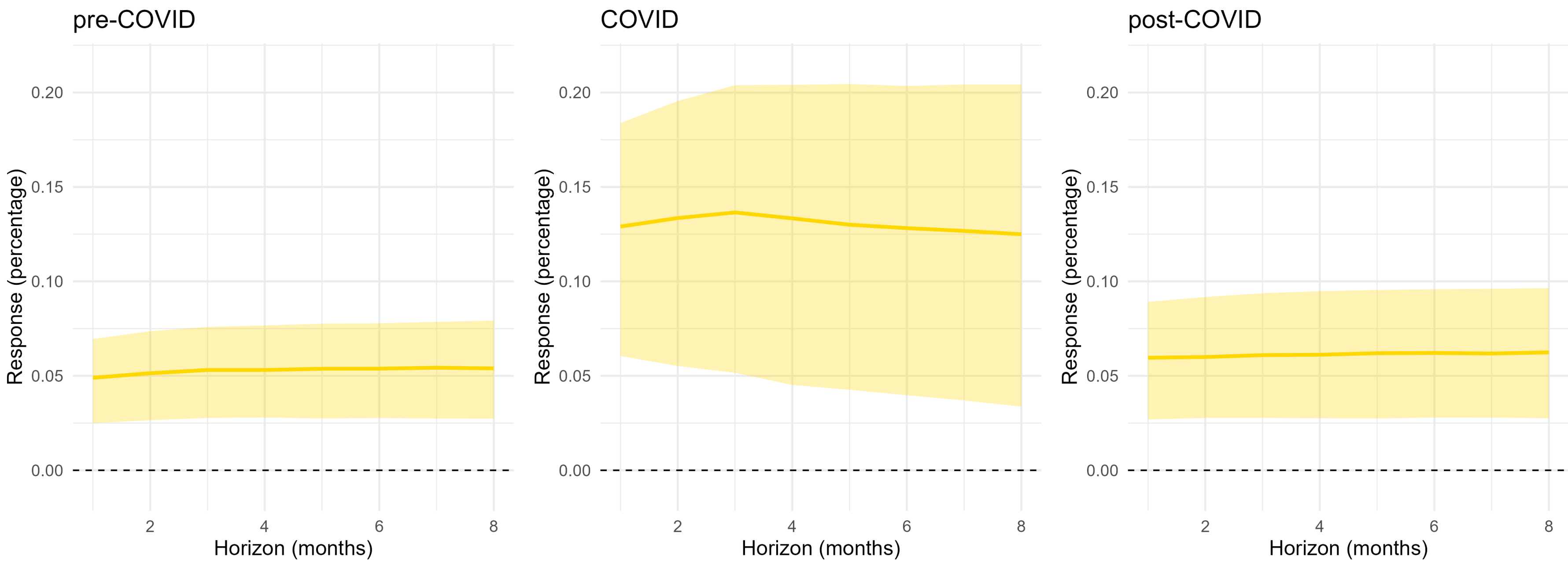
In the European Union, it can be observed how the impulse response of interest rates to a monetary policy shock is appreciably lower during the pre-COVID period than in the two subsequent periods. In more detail, it turns out that during the pre-COVID period monetary policy shocks engendered persistent increases in the overnight interest rate of approximately 2%. This implies that, at least during the first eight months (time horizon contemplated by the IRFs), a

Figure V.11: Impulse response function of the overnight interest rate in the EU



Source: Own elaboration.

Figure V.12: Impulse response function of the overnight interest rate in the USA



Source: Own elaboration.

unit and punctual monetary policy shock generated successive increases in interbank market interest rates of 2% monthly. In contrast to this pre-pandemic situation, we can contrast how these persistent responses to shocks became more than 10% and almost 7% during the COVID and post-COVID periods respectively. This means that, in both cases, and relative to the pre-pandemic period, the effect of monetary policy on interest rates was more than triple.

Something similar is observed in the United States. The pre-COVID period is characterized by the most modest response rate with a 5% instantaneous but also persistent response over time; the COVID period presents the highest sensitivity with a persistent percentage change of more than 12.5%; and the post-COVID period exhibits a response rate slightly above 5%.

At a comparative level, we can say that during the pre-COVID period it can be observed that monetary policy had a greater effect on interest rates (both immediate and sustained) in the United States than in the European Union. At the same time, both economies present an accentuated effectiveness of monetary policy on interest rates during the COVID-19 health crisis, observing response rates that, in both cases, exceed 10 percentage points. In contrast, after the pandemic, while the United States returns to values similar to those before COVID, the European Union does not return to its initial values and, in fact, seems closer to the North American economy. This seems to show that, regarding sensitivity to monetary policy, the post-COVID European Union resembles the United States, both before and after the pandemic.

V.3.2 Overnight interest rate - interpretation

The identical shape of the IRFs referring to interest rates in the three subperiods is explained because the central bank's official interest rate constitutes the main financing window alternative to the interbank market for commercial banks and other financial operators, and movements in official rates are transferred notably and almost immediately to the overnight interest rate. Thus, there is a direct and permanent link over time between changes in official rates and the overnight rates negotiated in the interbank market, which explains the straight shape of the IRFs.

Starting with the EU, it should be noted that, by the end of the 2010s, European interest rates were already notably reduced due to anti-recession efforts by public authorities. In this context, the effect of monetary policy on interest rates was the smallest of the three studied subperiods. With negative interest rates, it was difficult to push for further reductions through monetary policy, which explains the modest impulse response observed. This result seems to reinforce the idea that, indeed, the European Union was close to a *liquidity trap* emerging from the Great Recession.

During the COVID period, characterized by extraordinary interest rate hikes, the models indicate an accentuated impact of monetary policy on overnight rates, especially compared to previous periods. In the European Union, restrictive policies caused persistent increases of about

12 percentage points monthly, while in the United States the increase was slightly higher, about 14 points, with similar frequency and persistence. This dependence of interbank markets on central banks' financing window means that the direction of monetary policy has a great impact on overnight rates among financial institutions. When economic circumstances are favorable, the abundance of resources and alternative creditors means that the relationship between official and overnight rates weakens slightly. However, in difficult times, when central banks become the main creditors, their power over interest rates increases. Moreover, non-conventional monetary policies, such as QE, which involve the direct acquisition of corporate debt securities, further reinforce the influence of monetary authorities on interest rates compared to periods of relative normality.

The resemblance that the European Union presents with the United States before and after the pandemic is most certainly due to the fact that, emerging from the health crisis, both economies presented similar circumstances and, therefore, the response of financial markets to their monetary policies showed comparable characteristics. This situation contrasts with the year 2015, when tensions on European and North American markets were of a very different nature.

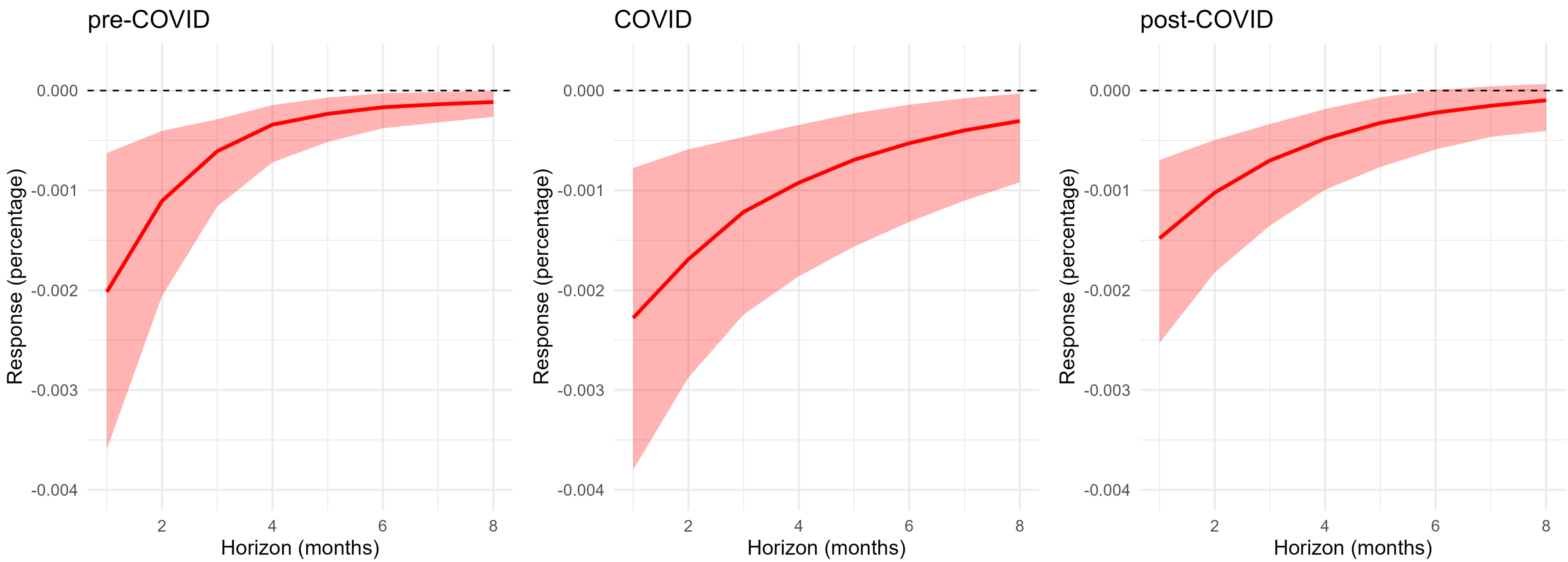
V.3.3 Inflation rate - results

Unlike when we studied the IRFs associated with overnight interest rates, the impulse responses of the inflation rate to monetary policy shocks require an analysis that deals simultaneously with both the magnitude of the impact and the shape of the function. This is because, as can be seen in the attached graphs, the shape of the IRFs is no longer a straight line, but a concave upward curve, indicating that, after exerting a negative influence on the inflation rate, restrictive monetary shocks gradually lose their effects as the months progress.

Regarding the analysis, it is observed that, in percentage terms, during the pre-COVID period, the response of the inflation rate to the same monetary policy shock is higher in the European Union (with an instantaneous impact of -0.2%) than in the United States (-0.1%). Despite this difference in magnitude, the truth is that the time until the extinction of the effects of monetary shocks on the inflation rate is almost identical in both economic areas: around the fifth month after the shock, it can be seen that the impulse response of the price change rate is practically zero both in the euro area and in North America.

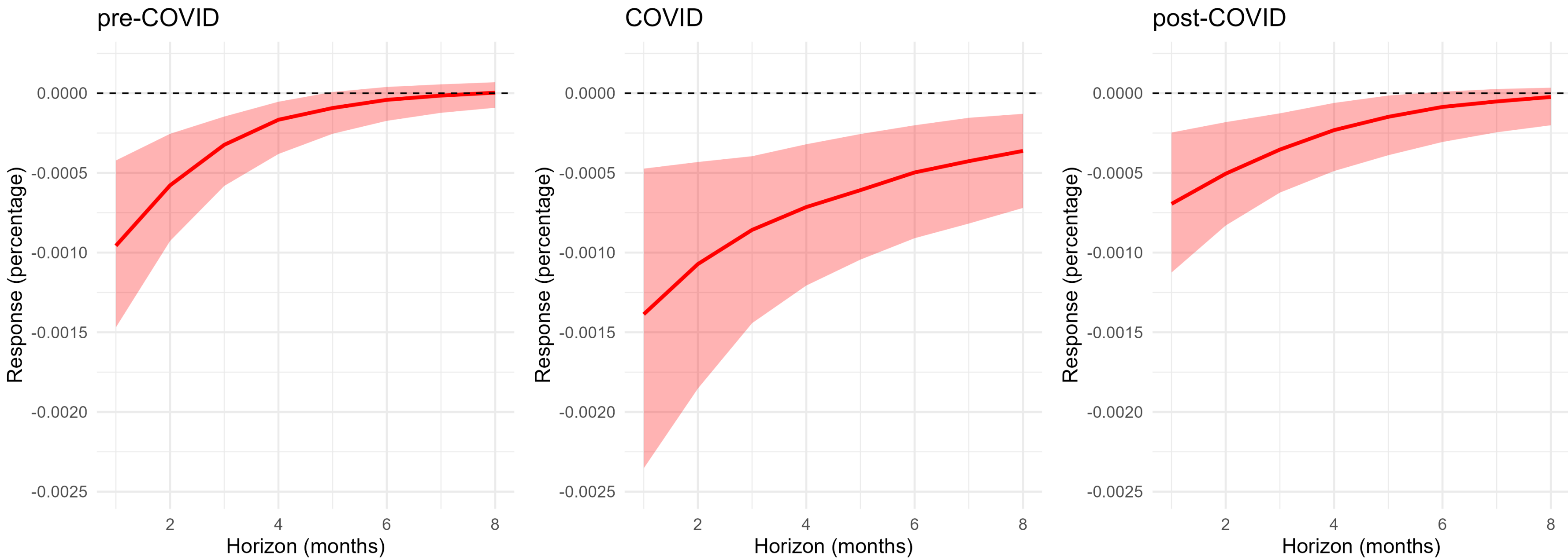
In both economies it is observed that, during the COVID period, the impact of monetary policy on the inflation rate was higher than in the previous and subsequent periods. In the European Union, relative to the pre-COVID period, the magnitude of the instantaneous impulse response increased modestly, exceeding 0.2 percentage points. However, the most notable change was the persistence of the shock: while in the pre-COVID period the effects had extinguished around the fourth month, in the COVID period effects of 0.1 percentage points were still recorded in

Figure V.13: Impulse response function of the inflation rate in the EU



Source: Own elaboration.

Figure V.14: Impulse response function of the inflation rate in the USA



Source: Own elaboration.

the fourth month (a little more than half of the initial impact). The complete extinction of the effects, which previously occurred in the fifth month, in this new period extended beyond the eighth.

In the United States a similar but more accentuated dynamic is observed. Starting from a situation with a relatively low impulse response of the inflation rate, from COVID onwards the instantaneous response to a unit and punctual monetary policy shock reached almost 0.15% (50% more than in the previous period). At the same time, the persistence of the effects of this shock also lengthened, with responses above 5 basis points until well into the sixth month.

Regarding the post-pandemic period, the IRFs of inflation show that, compared to the pre-COVID stage, the response of the inflation rate to monetary policy shocks is (1) of lower intensity in the short term and (2) of greater persistence in the long term. Before the pandemic, in the EU, a contractionary monetary policy shock exerted downward pressure on inflation for about four months; after the pandemic, this effect extends to approximately seven months. In the US a similar pattern is observed, although less accentuated.

In this last period, a significant difference in impact between Europe and the United States continues to be observed: European prices are approximately twice as sensitive to liquidity injections and restrictions by central banks.

V.3.4 Inflation rate - interpretation

Probably, the reason for the observed differences between the instantaneous response of the inflation rate between Europe and the United States lies in the different underlying inflationary tensions. In Europe, still immersed in the recovery process from the Great Recession and with a productive fabric under reconstruction, public stimulus policies failed to translate liquidity injections (negative monetary shocks) into increases in GDP, but mainly favored price increases. In the United States, on the other hand, the good health of the business fabric allowed it to more easily absorb cheap credit and, therefore, the price level was less affected by monetary policy.

Regarding the pandemic period, the difference in magnitude and duration of the effects of monetary policy relative to the periods before and after the health crisis can be explained, with high probability, as the product of an asymmetry in the effectiveness of this type of policy. The results seem to fit the theory of *"pulling on a string"* (which we explained in detail within the interpretation of the results of the historical decompositions of the output gap): when monetary policy has a predominantly restrictive objective—as happened during the last months of the pandemic—its effectiveness in cooling price increases is clearly reinforced. As Keynes said in his *Treatise on Money*:

> The attractiveness of an investment depends on the prospective income that the entrepreneur

> anticipates from his investment relative to the interest rate he has to pay in order to finance production. (Keynes, 2011, 154)

In this sense, although a reduction in interest rates can have an expansionary effect by making business projects attractive that, until then, and due to their opportunity cost, were not, the truth is that the consequence of an increase in rates is more severe for the economic fabric than its reduction. A substantial increase in interest rates will likely make business projects that were previously viable unfeasible, freezing or definitively interrupting ongoing initiatives, discouraging the start of new projects, preventing access to credit for families and firms (and thus restricting demand) and, in general, cooling aggregate economic activity very severely. This, in a context like that of COVID-19, explains, in part, why monetary policy had a greater impact on prices.

Finally, in the post-COVID scenario, and in accordance with Barrett and Platzer (2024), it is plausible to attribute the change in the speed of propagation of monetary shocks to the prevailing economic uncertainty in that period. In a context marked by trade and inflationary tensions, recession threats, and active military conflicts, it is most likely that the general level of uncertainty and instability caused a later and more gradual response from the various intermediaries, *dealers*, and *market-makers* that make up the steps of the monetary transmission chain.

V.3.5 Output gap - results

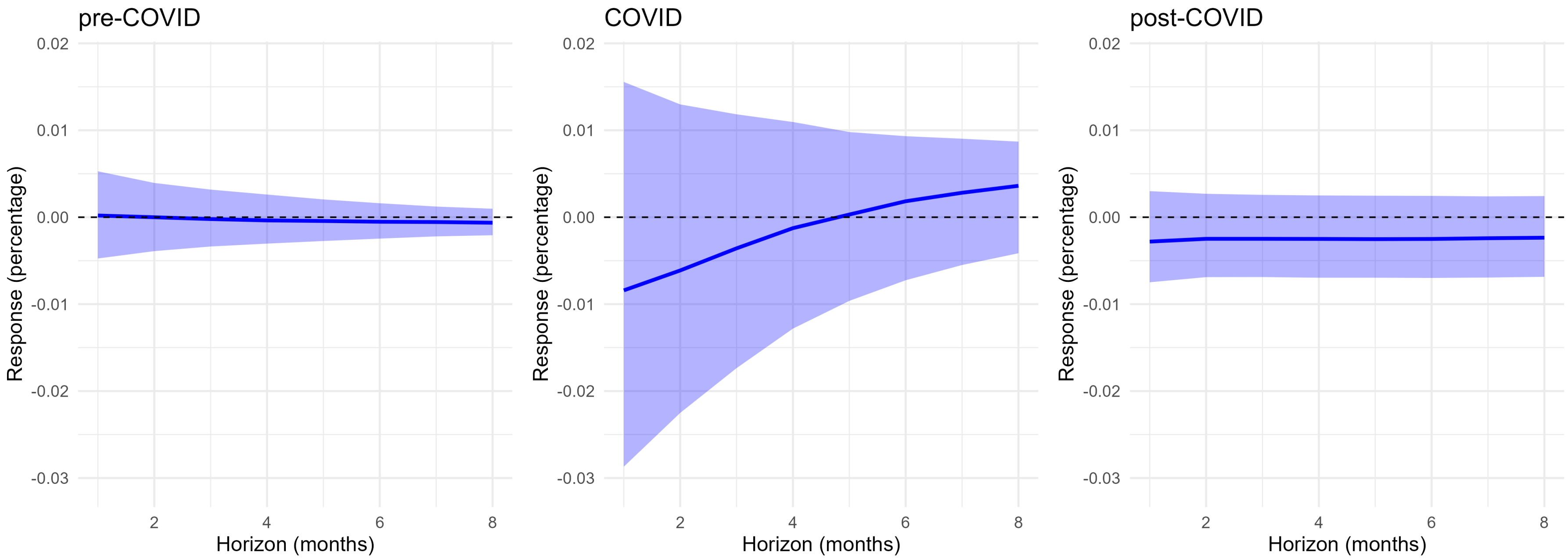
The first element that stands out from the six graphs is that, in general lines, the response of the output gap to monetary policy shocks in the two economies is very close to zero in all the studied subperiods. In fact, given the chosen credibility level (68%), we do not have enough evidence to affirm that, in any of the studied periods, monetary policy had significant effects on the output gap.[4] Thus, and although it may be interesting to comment on the differences between the shapes presented by these functions, it should be remembered at all times that we do not have enough evidence to consider them statistically different.

Starting with the North American economy, we can observe that during the pre-COVID period the effects of monetary policy are practically nil but slightly higher than those recorded in the EU. This scenario seems to reverse in the post-COVID period where, although we remain within the threshold of nullity, it seems that the effect of European monetary policy is more notable than that of the American one.

Another detail to highlight is that, in general, the IRF graphs of the United States seem to indicate that restrictive monetary policy could have a modest positive impact on the output gap. However, this result should be taken with skepticism, since—as we said—the bounds of the 68% confidence interval span both positive and negative values, suggesting high uncertainty

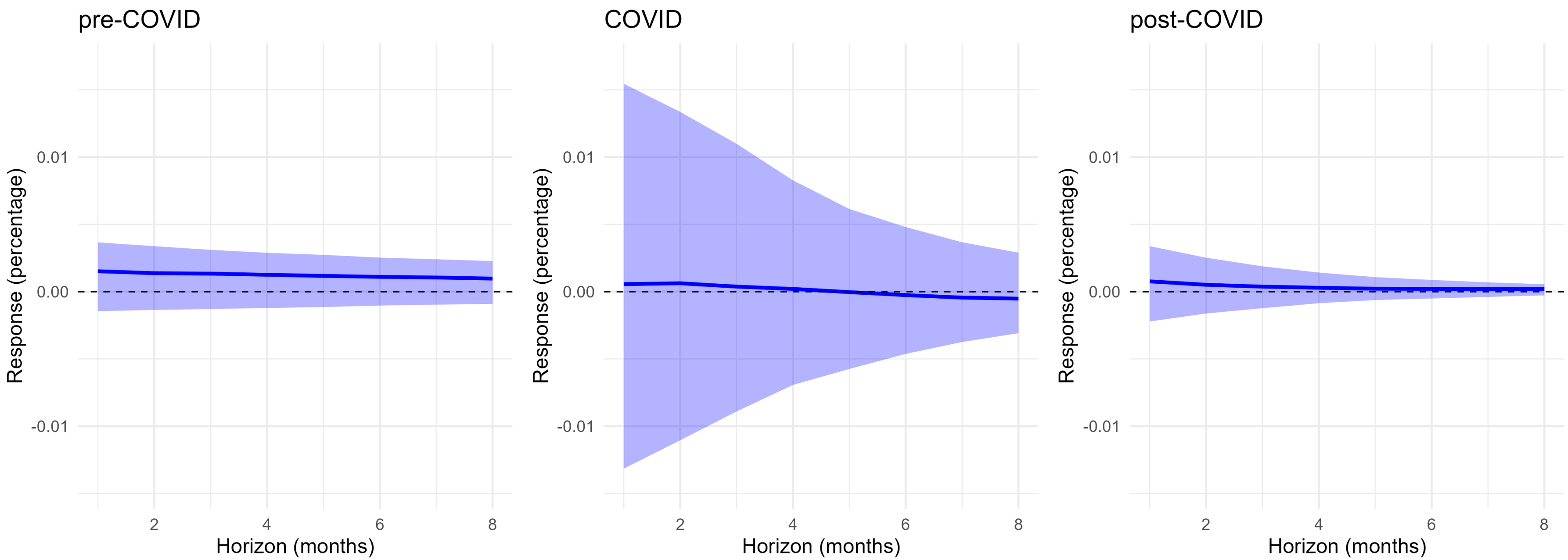
[4]In all of them the 68% credibility interval includes the value 0.

Figure V.15: Impulse response function of the output gap in the EU



Source: Own elaboration.

Figure V.16: Impulse response function of the output gap in the USA



Source: Own elaboration.

about the sign of the impact of the monetary shock on output. Moreover, the recorded impacts in percentage terms are very close to zero, so it is difficult to determine whether this effect on output is really significant and has a non-trivial economic interpretation.

Regarding the European Union, and in line with the HD graphs, it is observed that, although timidly positive at the beginning, the response of output to restrictive supply shocks is approximately zero.

The most surprising result appears in the shape of the IRF associated with the impact of monetary policy on the output gap during COVID. Although it should be interpreted with caution—given the width of the credibility interval, which leaves the door open to very diverse trajectories of opposite sign—the median of the IRFs suggests an initial predominance of negative values after a restrictive shock, indicating a modest contraction of economic activity (with an immediate effect of around -1%). Around the fifth month, however, this negative influence dissipates and the trend reverses, generating a positive impact on GDP.

Finally, and as already exposed in the analysis of the historical decompositions, in the European Union monetary policy shocks after the COVID crisis and of contractionary sign brought about a modest negative and sustained response of output.

V.3.6 Output gap - interpretation

As mentioned earlier, the main statistical conclusion we can draw from these IRF graphs is that, mostly, monetary policy did not have notable real effects in any of the economies or in any of the studied periods. To offer a plausible interpretation of these results, it seems necessary to combine theoretical insights from both New Classical Macroeconomics and New Keynesianism. It is well known that Keynes was skeptical about the possibilities of monetary policy in recessionary scenarios: when restrictions on growth come, on the one hand, from insufficiencies of aggregate demand (and, therefore, from an excess of liquidity or hoarding) or, on the other, from a paralysis of the productive fabric, monetary injection has very limited expansionary potential. In this sense, it should be noted that both the remnants of the Great Recession, typical of the pre-COVID-19 period, and the COVID-19 crisis, incorporate supply and demand components so marked that make it difficult for monetary policy to stimulate the real economy: no matter how much monetary capital is injected into the economy, the absence of viable business projects (caused by the financial collapse or by the restrictions derived from the pandemic), together with great uncertainty that froze demand and fueled hoarding, condemn any expansionary effort of this type to sterility. This is clearly seen in the COVID period in the United States: a high precautionary demand for cash *de facto* absorbed any increase in liquidity injected by monetary authorities, while the lack of business opportunities capable of taking advantage of cheap financing reinforced the sterility of monetary policy during the COVID era. Something similar can be said, for example, of the European Union in the pre-COVID and COVID periods.

From the perspective of New Classical Macroeconomics, the importance of expectations in explaining the effects of monetary policy must be emphasized. The fact that economic agents, during the last two decades, have become familiar with the inflationary effects of expansionary monetary interventions and have adapted their decisions accordingly means that the real effects of these policies are severely hampered. The effectiveness of monetary policy depends largely on its ability to surprise agents; if they foresee, for example, an increase in the money supply that will decrease their purchasing power, they will quickly adjust prices upward and neutralize any attempt to affect the real economy through liquidity injections. As explained in the section dedicated to historical decomposition, the anticipation of an inflationary process—if not accompanied by strong anchoring of expectations—produces dynamics such as wage renegotiation, anticipated sales, or deferred purchases that convert the effects of monetary policy into purely nominal.

Having made the general and statistically most rigorous interpretation of the effects of monetary policy on the output gap, we can sketch some brushstrokes on the particular patterns and idiosyncrasies presented by some of the IRFs in this subsection.

Considering the COVID-19 period in the European Union, the apparently erratic behavior of the IRF—which starts with negative values and ends with positive values—can be explained by referring to the structural and institutional circumstances proper to this period. Initially, the immediate effect of a restrictive monetary policy was the contraction of GDP, as usual when the objective is to cool a demand for goods and services that fuels inflation. However, despite these contractionary effects in the short term, the positive contribution of this policy to disinflation and the return to greater economic normality may justify the partial reversal of negative effects as the months after the shock progressed. In this case, the IRF reveals a temporal *trade-off* between the immediate contractionary effects and the more expansionary long-term effects derived from its stabilizing and disinflationary impact.

Regarding the slight positive bias observed in the effects of a restrictive monetary policy in the United States during the post-COVID-19 period, a plausible explanation is that the application of contractionary measures acted as a reinforcement of investor and business confidence in the structural solidity of the North American economy, thus contributing to expand the output gap.

Finally, closing the analysis of the post-COVID-19 period, the slight contractionary effect—immediate and persistent—that monetary policy had on the output gap is probably explained by the greater rigidity of the price structure in the European Union. Due to relatively high nominal rigidities—especially in wages, but also in prices of certain goods, services, and productive factors—the EU tends to experience non-trivial real impacts of monetary policy, i.e., a short-term non-neutrality of money. This sensitivity of real variables such as GDP means that, in the face of restrictive policies applied for disinflationary purposes after the pandemic, European economies had to bear a reduction in part of their aggregate income as a direct consequence of the action of monetary authorities.

Conclusions

After the extensive analytical exercise developed in the last chapter, only two main tasks remain: connecting the model results with the literature mentioned at the beginning of the work and presenting the most relevant findings in a synthetic manner. The first part will be devoted to exploring the main convergences and divergences between our findings (especially those related to HDs and IRFs) and the academic literature. The second part will summarize, clearly and in an orderly fashion, the most significant results obtained for each studied variable. Finally, under the title "On the Role of Monetary Policy in Exogenous and Systemic Crises", I will include a brief closing reflection aimed at placing the results in an economic policy perspective and extracting lessons applicable to situations similar to COVID-19.

V.4 Relation to the Literature

Although some interpretative sections of the previous chapter have already explored the relationship between our results and those of other authors, we have considered it appropriate to dedicate this brief section to make these connections more explicit and to situate the present research within the state of the academic art.

We will begin by reviewing the concordances between our findings and the existing literature. Regarding the role of expectations and their anchoring, our evidence is consistent with the conclusions of Blanchard and Bernanke (2025, p. 33), who emphasize that «inflation expectations, especially short-run expectations, rose enough to put upward pressure on wages and prices but generally remained well-anchored.» Indeed, we observe that in North America it was possible to mitigate inflationary tensions without monetary policy having notable real effects on output—a fact that indicates a high level of anchoring—while the situation in the European Union is less clear. Regarding the real effects of monetary policy on aggregates such as output or employment during the COVID-19 crisis, our results—pointing to their nullity—concord with studies such as those by Lepetit and Fuentes-Albero (2022), Feldkircher, Huber, and Pfarrhofer (2021), and Arias et al. (2024), which also document very modest effects of monetary policy on these aggregates during the pandemic.

At a descriptive level, our historical decomposition of inflation coincides with Arias et al. (2024) in the interpretation that the Fed acted with a delay in tightening its monetary policy, which facilitated higher and more persistent inflation levels than would have been observed with a more timely response. Similarly, the change in the shape of the IRFs during COVID suggests a slowdown in certain monetary policy transmission channels, as also noted by Barrett and Platzer (2024). Regarding the causal diagnosis of post-pandemic inflation, we agree with Blanchard and Bernanke (2025, p. 33) in stating that the bulk of this inflation is fundamentally explained by the laxity of fiscal and monetary policies and not so much by wage-price spirals. The shock estimation we present at the beginning of Chapter V—where it is observed that in the first years of the pandemic monetary policy shocks were predominantly expansionary—aligns with the change in the Taylor rule identified by Camehl and Woźniak (2023) during the COVID-19 period. Finally, we agree with Yilmazkuday (2022) regarding the difficulties posed by the presence of the zero lower bound for the effective use of expansionary monetary instruments in developed economies.

Discrepancies with the existing literature are few and generally not very significant. For example, our diagnosis of post-pandemic inflation differs slightly from the interpretation proposed by Feldkircher, Huber, and Pfarrhofer (2021), who attributed a minor role to the expansionary monetary policy of 2020 in worsening the inflation scenario; this apparent discrepancy can be explained because those studies had less data and because the inflationary effects of expansionary policies materialized especially as COVID-19 related restrictions were lifted. Similarly, King (2023) suggests that the stabilizing effects of monetary stimuli on financial markets could spill over to macroeconomic aggregates; this spillover is precisely what we have not found robustly in our analysis.

V.5 Main Results

We will begin by briefly presenting the results associated with overnight interest rates:

1. In contrast to the United States, the monetary policy of the European Union had little effectiveness in further reducing interest rates during the pre-pandemic period. Probably, the extensive use of monetary stimuli as an instrument to exit the Great Recession and the sovereign debt crisis placed the euro area in a state of near-*liquidity trap*, which hindered subsequent interest rate cuts.

2. COVID-19 accentuated the interdependence between official rates and overnight rates: IRFs show more intense and more persistent responses during the pandemic period, indicating a notable increase in the sensitivity of overnight rates to policy shocks in this phase.

3. In the post-COVID-19 period, monetary policy regained a central role, especially in the European Union, and the sensitivity of the euro area approached that of the USA, with a clearly restrictive nature that pushed rates upward.

Next, we will do the same with the results related to the inflation rate:

1. Before COVID, the dynamics were contrasting: in the European Union expansionary monetary policies exerted a positive influence on prices, while in the United States—with the exception of the last months of 2019—the increase in the price level was mainly explained by supply factors. The direct contribution of monetary shocks to pre-pandemic inflation was, overall, relatively modest and difficult to quantify accurately when the series presented values close to zero.

2. During the middle and final phase of the pandemic, a notable shift occurred: inflation increased sharply in both regions and, although monetary shocks were not the main driver initially, from the second half of 2022 their participation became significant and often of opposite sign to supply shocks. In the United States it is observed that the Fed acted with a delay (*too late*) in implementing monetary brakes, which fueled post-pandemic price increases. Simultaneously, the impact of monetary shocks on inflation was magnified and their duration lengthened, suggesting a slowdown in transmission mechanisms.

3. In the post-COVID period, monetary policy managed to mitigate inflation by mid-2023, but subsequently a divergence emerged: between late 2024 and 2025 monetary shocks exerted persistent upward pressures in the EU (very high positive contribution in the last months), while in the USA the contribution was substantially lower or even of opposite sign.

Finally, we will present the results associated with the output gap:

1. In broad terms, monetary policy did not have statistically significant effects on the output gap in any of the studied periods. This, with high certainty, is due to the conjunction of supply constraints (destruction of the productive fabric) and demand constraints (high uncertainty and hoarding) that rendered attempts to stimulate the economy through liquidity injections sterile.

2. During the COVID phase, monetary policy showed an overall marginal effect on the output gap: average contributions were small and statistical uncertainty was high, so the observed effects on GDP are weak and inconclusive.

3. Although these are modest and inconclusive differences, before the pandemic a greater effectiveness of monetary policy was observed in the United States than in the European Union, and this pattern reversed in the post-COVID period. The first phenomenon is

probably explained by the state of near-*liquidity trap* in which Europe found itself and by the superior integration of North American financial markets; the subsequent reversal of the scenario could be related to episodes of relative dollar weakness and the evolution of international trade tensions.

V.6 Final Reflection: *On the Role of Monetary Policy in Exogenous and Systemic Crises*

Although it was Lionel Robbins who first explicitly mentioned the central importance of satisfying human needs within the edifice of economic science, the fact is that this conception seems to be implicit in the great majority of his predecessors. From the first Greek thinkers who, like Xenophon, were interested in the management of resources at the level of the Greek *polis*, through our Scholastics of the Golden Age who—for the first time—intuited the subjective nature of the value of exchanged goods, to the British and Scottish classical economists who systematized the treatment of economic affairs, the central idea that economic action had as its ultimate end the satisfaction of human needs always permeated the writings of past economists. However, and over time, the illusory construction of *homo oeconomicus*, as a different and separate dimension of the usual conduct of man, began to become evident. As thinkers such as Jeremy Bentham or John Stuart Mill stated, in reality, the principle according to which people always and at all times seek to maximize their happiness applies not only to their economic or commercial affairs, but to the whole of human action. This implies that, in fact, the notion of satisfying needs is not limited to economic science, but encompasses and permeates the whole of social sciences: from sociology, to political science, through history and anthropology.

Having said that, we can now properly speak of monetary policy, which is nothing more than a small parcel of the economic policy of monetary and financial authorities, and this, a subset within the aggregate of public policies. Although on rare occasions, and perhaps more frequent in earlier periods of economic history, monetary policy has not always obeyed collective interests and has been dragged along by the partisan interests of politicians, lobbyists, and other interest groups, the truth is that, in recent times, it is difficult to attribute private interests to the experts who design the monetary policies of the major central banks (beyond international and/or geopolitical interests). With greater or lesser success, the economists of the Federal Reserve or the European Central Bank have devoted their best efforts to making monetary policy decisions that best serve the interests of the citizenry. This task of deciding and implementing monetary policies, although important under normal circumstances, acquires extraordinary new relevance when, for various reasons, economies go through periods of severe difficulty. In such circumstances, with a weakened economic fabric, with businesses and households seeing their incomes fall, and with consumers facing difficulties accessing the goods they desire, it is especially crucial that the decisions taken by our monetary and financial planners are as accurate as possible.

I speak of exogenous and systemic crises to refer to crises like that of COVID-19; crises because, during a more or less prolonged period, the economy enters recession and the main macroeconomic aggregates, together with the welfare of the citizenry, are severely eroded; exogenous because they come from phenomena alien to the usual functioning of market economies and are not attributable to factors such as stock market panics, planning errors, or others; and systemic because, instead of affecting only a particular economic parcel (raw materials, capital markets, international trade, etc.), they have repercussions on the whole economic system. This type of crisis, fortunately uncommon, are, compared to conventional boom and recession cycles, relatively more harmful, both in terms of human lives and material welfare. For this reason, it is of vital importance that the monetary policy of our leaders is adequately prepared to face circumstances like these.

In this sense, the task of academics, researchers, and economists in general lies in providing *insights* and practical recommendations to help guide the decision-making of regulators and, thus, contribute to overcoming these social adversities in the smoothest way possible. Understanding the very modest possibilities of a study like the present one, it seems to me that some of the results obtained during the last pages can be helpful in designing monetary policy programs to face future exogenous-systemic crises like that of COVID-19.

More specifically, and in line with the main conclusions of the work, it seems clear that where uncertainty prevails and where the economic and productive fabric is severely damaged due to all kinds of adversities, the capacity of monetary policy to help is severely compromised. In circumstances such as those described, where economic agents prefer to hoard means of payment and where, even if they wanted to spend them, there is no abundance of business and productive projects in which to invest them, the possibility of assisting society through liquidity injections is very modest. Without this necessarily implying a renunciation of any alternative public policy effort to counteract the ills of the crisis, it seems to me that, in order to better manage the scarce resources available to our institutions and planners, the most convenient thing is to recognize that, in general, monetary policy is weak in these cases and, therefore, it would be better to seek alternative avenues of assistance.

However, someone could object—and with good reason—that, in fact, even if the effects of monetary policy on the income of the inhabitants are very modest or almost nil, insofar as this allows certain households and businesses to avoid bankruptcy, we already have sufficient justification to undertake measures of this type. Despite the laudable aspirations of this criticism, it seems to me that making a modest use of monetary policy in contexts like this remains the path to follow. And it is that, although indeed, such policies could have marginally beneficial effects on the social fabric, these positive effects pale in comparison to the pernicious consequences they can entail in the medium and long term. As this study demonstrates, the inflationary tensions accumulated during the first half of the pandemic (due to public spending, supply insufficiencies, but also monetary injections) and which exploded during the second half, have caused damage of a very severe magnitude, and which, most certainly, could have been avoided had such extensive use of monetary policy not been made. The inflationary escalation of 2022, which required an urgent and severe use of monetary policy (now, very effective) to cool economic activity and put a brake on price increases, although it allowed exiting the pandemic recession a little earlier than would have been possible without the injections, also implied a much longer subsequent adjustment period, which has translated into additional recessions and very severe monetary and financial restrictions. If, instead of trying to escape the COVID-19 recession at all costs, the economic fabric had been allowed to heal itself and spending to grow at a pace similar to the production of businesses, we could have saved a large part of the hardships that, to this day, we still drag within Western economies.

This is not a manifesto against monetary policy, but a call for prudence. To use a medical analogy, although a little stimulant can be beneficial for a patient in a state of lethargy, overdoing the dose, although it will certainly wake him up prematurely and allow him to resume his functioning more quickly, will most certainly also cause more damage, and a greater crashout once the effects of the medication wear off. In the same way, and although it may be interesting to use monetary policy in certain contexts of an exogenous and systemic crisis, I postulate that the most intelligent thing is to make very moderate use of it and rather disinflationary than expansionary. On the contrary, it seems to me that we would be exchanging a present but fleeting welfare, for a future but lasting welfare.

And all this without taking into account the microeconomic misalignments (at the level of relative prices of productive factors) that massive monetary injections could trigger in an economy in the process of recovery. However, these considerations exceed the scope of this study, as we have only studied the macro impacts of this kind of policies.

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Appendices

V.7 Appendix A: Optimization of Consumption Expenditure Decisions

Following Galí (2015, 61-62), the optimization problem faced by households can be described according to the following Lagrangian:

$$\mathcal{L} = \left[\int_0^1 C_t(i)^{1-\frac{1}{\epsilon}} di\right]^{\frac{\epsilon}{\epsilon-1}} - \lambda \left(\int_0^1 P_t(i)C_t(i)di - Z_t\right)$$

where Z_t is a given level of expenditure.

The first-order conditions associated with this Lagrangian - obtained by setting the partial derivatives to zero - are as follows:

$$\forall i \in [0,1] : \frac{\partial \mathcal{L}}{\partial i} = C_t(i)^{-\frac{1}{\epsilon}} C_t^{\frac{1}{\epsilon}} - \lambda P_t(i) = 0 \implies C_t(i)^{-\frac{1}{\epsilon}} C_t^{\frac{1}{\epsilon}} = \lambda P_t(i)$$

Given any pair of goods (i, j), and knowing that $\int_0^1 P_t(i)C_t(i)\partial i = P_t C_t \equiv Z_t$, then we can obtain the demand scheme expression as presented in the model:

$$C_t(i) = C_t(j)\left(\frac{P_t(i)}{P_t(j)}\right)^{-\epsilon} = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} \frac{Z_t}{P_t} = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} C_t$$

V.8 Appendix B: Optimal Conditions for Investment and Labor Supply

As in the previous case, in order to discover the optimality conditions for households regarding investment and labor supply, we first need to describe the problem through a Lagrangian that integrates the infinite set of time periods:

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t \left[U(C_t, N_t) - \lambda_t \left(P_t C_t + Q_t B_t - B_{t-1} + W_t N_t - T_t \right) \right]$$

To arrive at the first-order conditions of the optimization problem, we need to obtain the partial derivatives of the Lagrangian for each period:

$$\forall t = 1, 2, \ldots : \begin{cases} \frac{\partial \mathcal{L}}{\partial C_t} & = \beta^t \frac{\partial U(C_t, N_t)}{\partial C_t} - \lambda_t P_t = 0 \\ \frac{\partial \mathcal{L}}{\partial N_t} & = \beta^t \frac{\partial U(C_t, N_t)}{\partial N_t} - \lambda_t W_t = 0 \\ \frac{\partial \mathcal{L}}{\partial B_t} & = \beta^{t+1} E_t\{\lambda_{t+1}\} - \beta^t \lambda_t Q_t = \beta E_t\{\lambda_{t+1}\} - \lambda_t Q_t = 0 \end{cases}$$

The expression $-\lambda_t Q_t + \beta E_t\{\lambda_{t+1}\} = 0$ appears as a first-order condition with respect to bonds B_t, because they affect two temporal stages: they represent a current expenditure in period t (with marginal cost $\lambda_t Q_t$) and a future income in period $t+1$ (with expected marginal benefit $\beta E_t\{\lambda_{t+1}\}$). The term $\beta E_t\{\lambda_{t+1}\}$ reflects that agents make decisions at t taking into account the expectation of the marginal value of future income, properly discounted by the factor β. Thus, the condition expresses the optimal intertemporal equilibrium: the marginal cost of saving today must equal the expected marginal benefit of consuming more in the future.

Combining the first two conditions, we can find the optimal relationship between the marginal utilities of consumption and labor with their respective prices:

$$\beta^t \frac{\partial U(C_t, N_t)}{\partial N_t} \frac{1}{W_t} = \lambda_t = \beta^t \frac{\partial U(C_t, N_t)}{\partial C_t} \frac{1}{P_t} \implies \frac{\frac{\partial U(C_t, N_t)}{\partial N_t}}{\frac{\partial U(C_t, N_t)}{\partial C_t}} = \frac{W_t}{P_t}$$

At the same time, combining the first with the last, observing that $\lambda_t = \frac{\beta^t \frac{\partial U(C_t, N_t)}{\partial C_t}}{P_t}$, we can arrive at the second optimality condition:

$$\beta E_t\{\lambda_{t+1}\} - \lambda_t Q_t = 0 \implies Q_t = \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \right\} \implies Q_t = \beta E_t \left\{ \frac{\frac{\partial U(C_{t+1}, N_{t+1})}{\partial C_{t+1}}}{\frac{\partial U(C_t, N_t)}{\partial C_t}} \frac{P_t}{P_{t+1}} \right\}$$

V.9 Appendix C: Development of Price Dynamics

Denoting by $S(t) \subset [0, 1]$ the subset of firms that cannot update their prices in period t, and assuming that, if they could, all firms would set an optimal price P_t^*, the general price level can be described as:

$$P_t = \left[\int_{S(t)} P_{t-1}(i)^{1-\varepsilon} di + (1-\theta)(P_t^*)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$
$$= \left[\theta(P_{t-1})^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$

Dividing both sides of the equality by P_{t-1} we can obtain the expression for the gross inflation rate:

$$\Pi_t^{1-\varepsilon} = \theta + (1-\theta)\left(\frac{P_t^*}{P_{t-1}}\right)^{1-\varepsilon}$$

where $\Pi_t \equiv \frac{P_t}{P_{t-1}}$. This equation can be log-linearized giving us the following expression:

$$\pi_t = (1-\theta)(p_t^* - p_{t-1})$$

V.10 Appendix D: Formal Description of Integration and Cointegration Tests

Below, we present concisely and formally the three main tests for assessing the stationarity of time series: the Dickey-Fuller test with GLS correction (DF-GLS), the Phillips-Perron test (PP), and the KPSS test.

DF-GLS Test (Elliott, Rothenberg and Stock, 1996)

Consider the following specification for the transformed time series $\tilde{y}_t$, obtained via a GLS transformation designed to remove non-stationary deterministic components:

$$\tilde{y}_t = \phi\tilde{y}_{t-1} + \sum_{j=1}^{p} \gamma_j \Delta\tilde{y}_{t-j} + \varepsilon_t,$$

where ε_t is white noise, and the number of lags p is chosen according to information criteria. The null hypothesis is formulated as $H_0 : \phi = 1$ (presence of a unit root), while the alternative hypothesis is $H_1 : \phi < 1$ (stationarity). The test statistic is similar to the classic ADF, but applied to the transformed series $\tilde{y}_t$. Its distribution is non-standard and critical values are obtained by Monte Carlo simulation.

Phillips-Perron Test (1988)

This test adjusts the Dickey-Fuller test to correct for possible heteroskedasticity and autocorrelation in the residuals using a non-parametric estimation of the covariance matrix. The statistic is defined as

$$Z_\alpha = t_\alpha - \frac{\hat{\sigma}^2 - s^2}{2s} \cdot \left(\frac{T}{\sum_{t=1}^{T} y_{t-1}^2} \right),$$

where t_α is the t statistic from the Dickey-Fuller regression, s^2 is the uncorrected variance of the error term, and $\hat{\sigma}^2$ the variance corrected using robust estimators such as Newey-West. The null hypothesis is the presence of a unit root (H_0), while the alternative is stationarity (H_1). The distribution of the statistic is identical to that of the ADF test and does not follow a standard χ^2 or normal distribution.

KPSS Test (Kwiatkowski, Phillips, Schmidt and Shin, 1992)

This test poses the null hypothesis of stationarity of the time series around a mean or a deterministic trend, while the alternative corresponds to the presence of a unit root. The KPSS statistic is based on the cumulative sum of the residuals from the deterministic regression:

$$\text{KPSS} = \frac{1}{T^2} \sum_{t=1}^{T} S_t^2 / \hat{\sigma}^2,$$

where $S_t = \sum_{i=1}^{t} \hat{\varepsilon}_i$ is the cumulative sum of the residuals $\hat{\varepsilon}_i$, and $\hat{\sigma}^2$ is a consistent estimator of the white noise variance. Unlike the previous tests, high values of the KPSS statistic lead to the rejection of the null of stationarity. Critical values are obtained by simulation, as its distribution is non-standard.

V.11 Appendix E: Details on the Compact Form of the Reduced VAR

The compact notation of the reduced-form VAR model, $Y = XB + \mathcal{E}$, defines the matrices that constitute it as follows:

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_T \end{pmatrix}, \quad X = \begin{pmatrix} y_0 & y_{-1} & \cdots & y_{1-p} \\ y_1 & y_0 & \cdots & y_{2-p} \\ \vdots & \vdots & \ddots & \vdots \\ y_{T-1} & y_{T-2} & \cdots & y_{T-p} \end{pmatrix}, \quad B = \begin{pmatrix} A_1 \\ A_2 \\ \vdots \\ A_p \end{pmatrix}, \quad \text{and} \quad \mathcal{E} = \begin{pmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_T \end{pmatrix}$$

Basically, Y is a $T \times n$ matrix containing the observations of the endogenous variables; X is the $T \times (np + 1)$ matrix of regressors, which includes the lags of the variables and a constant (if applicable); B is the $(np + 1) \times n$ coefficient matrix; and $\mathcal{E}$ is the $T \times n$ matrix of residual errors.

This expression can be converted into a vector equation—more appropriate for most estimation methods such as Ordinary Least Squares (OLS)—by vectorizing its matrices, that is, transforming the matrices into vectors by "stacking" their values column-wise (greatly increasing their number of rows):

$$y = \bar{X}\beta + \epsilon$$

where:

$$y = \mathrm{vec}(Y), \bar{X} = I_n \otimes X, \beta = \mathrm{vec}(B), \epsilon = \mathrm{vec}(\mathcal{E}) \sim N(0, \bar{\Sigma})$$