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The long-run effects of monetary policy shocks: Theory and empirical evidence

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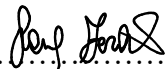
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INTRODUCTION

While it is widely accepted that monetary policymakers can stimulate or cool down an economy in the short term, according to classical economics their influence becomes limited over longer periods of time. In this sense, the "independence hypothesis" as referred to by Blanchard (2018), suggests that the conduct of monetary policy is often assumed to be separate from the productive capacity of the economy in the long-term.

Over the years, some economists have started to gather evidence against this theory and proposed a case for long-term effects of monetary policy. During the 2010s, there was growing concern regarding the sluggish pace of productivity growth, leading to suspicions that policymakers might be downplaying their own impact. As a result, a limited but increasing body of research has shown a keen interest in understanding the potential long-term consequences of monetary policy (Financial Times, 2023). Some scholars have explored how monetary policy may affect innovation and technological progress.

This thesis will start by presenting an overview of the IS-LM model, enabling readers to refresh their knowledge of the traditional economic perspective prior to exploring more recent literature that challenges monetary policy neutrality.

The second chapter provides a concise review of the emerging literature that disputes long-term monetary neutrality. Fornaro and Wolf (2023) tackle the topic by focusing on the impact of monetary policy at the firm-level. More specifically, their research builds a framework connecting monetary policy with the businesses' decisions on their mix of labour and capital. Ma and Zimmerman (2023) also focus on the influence of monetary policy on innovation, which takes place through changes in aggregate demand and changes in financial conditions. Particularly, the authors choose to concentrate on monetary policy's impact on R&D spending, patenting, and VC investments. Another contribution comes from Jordà, Singh and Taylor (2023), who perform long-run cross-country analyses to identify exogenous monetary policy fluctuations and measure long-run output effects.

The final chapter includes an empirical investigation to assess whether monetary policy shocks have long-term effects on the natural interest rates and other variables. The study will be carried through an analysis based on a SVAR approach à la Plagborg-Moeller and Wolf (2021) and incorporating a proxy à la Miranda-Agrippino and Ricco (2021). The central objective is to scrutinize and assess whether the conventional wisdom of monetary neutrality remains a valid and robust concept in light of empirical evidence. This exploration seeks to clarify the extent to which monetary policy actions can exert a lasting influence on the natural interest rate, challenging or reinforcing established economic paradigms.

CHAPTER 1

This chapter aims to offer an overview of the IS-LM model, allowing readers to brush up their understanding of the traditional economic perspective before delving into the more recent literature that challenges monetary policy neutrality.

1.1 A brief history of the IS-LM model

When British economist John Maynard Keynes wrote “General Theory of Employment, Interest and Money” (1936), the book had been described as a major pillar for modern economics by scholars of the time. The work was, however, quite difficult to understand. A year later, John Hicks (1937) synthesized what he considered to be the biggest contribution by Keynes: the joint description of the goods market and the financial market. His analysis was later expanded by Hansen, with whom he formalized it as the 'IS-LM model'.

This model provided an alternative for studying a nation's economy in the short run. Because it focuses on the short run, the model assumes viscous prices: this assumption is consistent with reality because in the short run businesses cannot change prices immediately.

Despite receiving a fair amount of criticism, especially since the late 1970s, it still plays a vital role in shaping the progress of the contemporary global economy. This is due to its simplicity, which manages to accurately capture a significant number of immediate economic impacts.

The IS-LM model serves as a foundation for numerous econometric models used by public authorities and businesses to make political and economic forecasts. A significant factor contributing to the success of the IS-LM model undoubtedly lies in its ability to generate numerous insights through its analytical and heuristic nature, all using simple theoretical tools. On that note, the model has the ability to outline the entire demand side of an economy using a mere two equations and two endogenous variables (income or output and interest rate). This simplicity allows it to potentially be categorized as one of the most linear yet meaningful models for analysing the interactions between the goods and money markets within an economy.

In addition, the radical straightforwardness that characterizes the model and the ability to visualize it with a two-dimensional graph make it possible to intuitively check its implications for economic and policy analysis, while at the same time enabling smooth communication between macroeconomists and the wider audience.

Indeed, a crucial contribution made by the IS-LM model over the years is the provision of an interpretative framework, which helped elucidate the interpretations of certain economic theories when compared with others. In fact, the model always played a crucial role in

theoretical and policy discussions among macroeconomists and policymakers. On that note, Keynes himself characterized the model with the following words:

“The object of our analysis is, not to provide a machine, or a method of blind manipulation, which will furnish an infallible answer, but to provide ourselves with an organized and orderly method of thinking out particular problems; and, after we have reached a provisional conclusion by isolating the complicating factors one by one, we then have to go back on ourselves and allow, as well as we can, for the probable interactions of the factors amongst themselves. This is the nature of economic thinking. Any other way of applying our formal principles of thought (without which, however, we shall be lost in the wood) will lead us into error.”

JM Keynes, Chapter 21, General Theory

The IS-LM model assumes an additional role, which is descriptive and aimed at representing, explaining, or predicting the performance of a particular economy. Throughout the years, it has consistently served as a fundamental component in econometric models employed to examine economic behaviour and assess the efficiency of economies. This initial triumph can be attributed, at least partially, to its usage in the initial econometric research conducted during that period.

The model's last function is regulatory: it guides the selection and implementation of the most suitable fiscal and monetary policy rules and measures. Using various econometric models, several optimal policies have been identified that fit certain economies over specific periods of time. Therefore, it is evident why it continues to serve as a significant guiding tool for the development of monetary and fiscal policy strategies.

1.2 The underlying assumptions of the IS-LM model

As previously mentioned, the IS-LM model was introduced in 1939 by British economist John Richard Hicks as a tool for analysing the goods market and financial market together. Over time, it gained popularity among economic policy experts for outlining the necessary monetary and fiscal policies that should be implemented to address economic issues such as recession, unemployment, and high public debt. Hicks formulated the model based on certain assumptions that must always hold true for it to maintain its validity:

- Prices must be considered as given and constant. This means that any adjustments to the model will take place through changes in the quantities produced and the interest rate. Furthermore, this implies that the time frame to be considered within the model can only be the short run. This last assumption is not restrictive, as prices within the short term are necessarily viscous and therefore cannot be increased by the person setting them from one moment to the next.
- Investments must be considered endogenous, i.e., dependent on income and the interest rate, which acts as a transmission mechanism from the monetary sector to the real sector.
- Finally, the economy will be considered closed. In other words, both imports and exports are zero.

A key role in the model is assigned to the interest rate (i) and production (Y), which also represents the income level within the system. The relationship between production and income should not be confusing since they are essentially the same, representing different perspectives of GDP (respectively from the production side and income side).

With regard to the goods market, there is a specific value of Y that is in equilibrium for any value of i . This means that for any interest rate it is possible to find a value of income (or output) that aligns with equilibrium in the goods market. The graphical representation of this equilibrium relationship between i and Y is illustrated by the investment-savings (IS) curve. To know the equilibrium value of Y , it is crucial to determine the precise value of i , which can be done by examining the connection between the interest rate and the equilibrium in the money market. For any value of i , there is an equilibrium value of Y in the money market in which the demand for liquidity corresponds to the supply of money. This interaction between Y and i is represented by a curve called the money liquidity (LM) curve.

The intersection that will appear between the IS curve and the LM curve will determine the values of the interest rate and income level compatible with the simultaneous equilibrium of

the goods and money markets. Analytically, the above result will be obtained by simultaneously solving a system consisting of two equations representing one the IS relationship and the other the LM relationship.

1.3. The IS curve

The IS curve depicts the combinations of output and interest rates at which the goods market is in balance. In a closed economy, like the one under consideration here, the level of income (Y) is determined by the aggregate demand for goods, which comprises household consumption, business investments, and government expenditure on goods and services. The equation illustrating this relationship is as follows:

$$Y=C+I+G$$

Analysing each term on the right-hand side of the equation above, it is observed that: Consumption (C) is given by an autonomous component (c_0) plus a component (c_1) that depends on disposable income (Y_d). The latter is given by:

$$Y_d = Y - T$$

where Y is income and T represents taxes net of transfers (the value of taxes T will be considered exogenous for simplicity). The relationship between consumption and disposable income can thus be represented linearly through the following equation:

$$C = c_0 + c_1 Y_d$$

Within the model, consumption (C) is considered an endogenous variable, as it is explained by other variables within the model. Instead, the parameters c_0 and c_1 represent the desired consumption at zero disposable income and the marginal propensity to consume, respectively. In the first case, the value of c_0 can never be less than zero, even if the hypothesis $Y_d=0$ was to occur. The explanation is quite straightforward; individuals must sustain themselves, regardless of whether they have a source of income or not. Consequently, in the latter scenario, people will inevitably depend on their savings or borrow money to get by. The value of parameter c_1 must be positive because an increase in disposable income leads to greater consumption by individuals. It will also have to be less than 1 because it is more than

likely that individuals decide to consume only part of their increase in income and instead want to keep what remains as savings. c_1 thus expresses the effect on consumption of an additional euro of disposable income. Indeed, this logic can be expressed through an equation representing consumption (C) as a function of the disposable income (Yd):

$$C = C(Y_d)$$

This equation describes the behaviour of consumers as economic agents in the goods market. If disposable income increases, consumption also increases.

The second term in the Y equation is investment (I), which primarily relies on two key elements; the interest rate (i) and the level of sales. When a company observes a growth in sales, it will have to expand its production capacity by procuring new machinery and equipment. In simpler words, the company will make investments. Conversely, if a company experiences a decrease in sales, there won't be any necessity for fresh investments.

If the value of i rises, it will result in a decrease in investment because the cost of financing also increases, making it more expensive to invest. For instance, if a company intends to purchase new machinery for production purposes, they may have to borrow money from a bank at a specific interest rate. The higher the interest rate, the less appealing it becomes to acquire debt for that new investment. Moreover, if the interest rate is very high, the future profits may not be sufficient to cover the interest payment on the bank loan, thus rendering the investment unprofitable. This concept is synthesized by the following formula:

$$V_I = \sum_{t=0}^T \frac{RN_T^e}{(1+i)^t} \geq P_k$$

The formula above shows the relation between the interest rate (i) and investments (I). Individuals invest when the present value of expected future benefits (V_I) - based on the expected net revenue at time t (RN_T^e) and the interest rate (i) - is greater than/equal to the investment amount (P_k).

In the model, investment is a function of the level of income and the interest rate: for a given level of Y, there's a planned level of investment for each value of the interest rate.

$$I = I(Y, i)$$

What has just been described can be observed from the Figure 1 below:

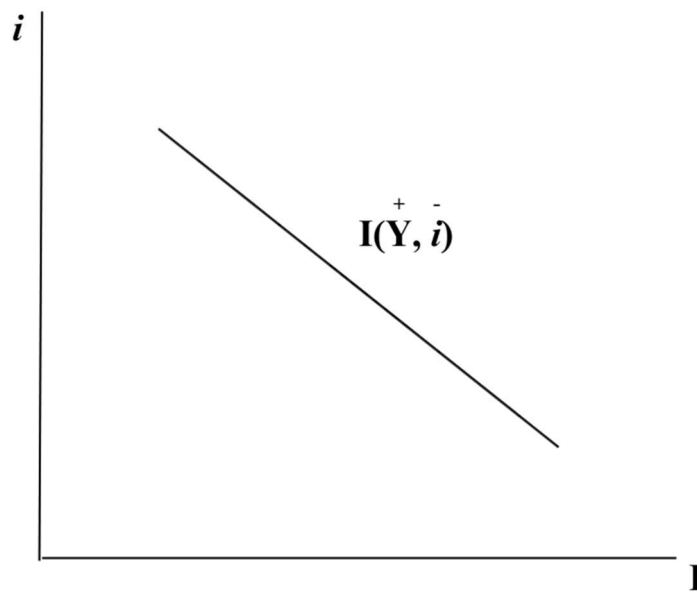


Figure 1: Relationship between investment (I) and interest rate (i)

In our model, investment will therefore be considered endogenous and can be represented by the following linear function:

$$I = I_0 + d_1 Y - d_2 i$$

While I_0 indicates independent investment expenditure, d_1 measures the sensitivity of investment to income; this is a positive relationship since an increase in sales corresponds to an increase in output within a given enterprise, which leads to the purchase of additional machinery and plant and thus to investment growth. Y represents the level of income or output. The sensitivity of investment to the interest rate, as measured by d_2 , exhibits a negative relationship. As mentioned before, an increase in the interest rate is followed by a decrease in investment. Finally, the real interest rate i , which was not mentioned above, which has the same value as the nominal interest rate.

The last term to be analysed within the equation is G , which represents government spending and, together with T taxes, is crucial to the fiscal policy choices made by governments. It is now possible to express the equilibrium condition in the goods market, that is, to determine the IS curve. Initially this curve will be presented through a nonlinear equation; only later, after also presenting the LM curve, a linear equation will be formulated for each of the two curves.

The equilibrium condition in the goods market becomes:

$$Y = C(Y - T) + I(Y, i) + G$$

As described earlier, the IS curve depicts all the combinations of Y and i that ensure equilibrium in the goods market; this curve will be negatively sloped, since an increase in the interest rate is always followed by a reduction in investment and thus, as could be observed earlier, a decrease in output also follows. This can be described, and made simpler, through the following graphical representation:

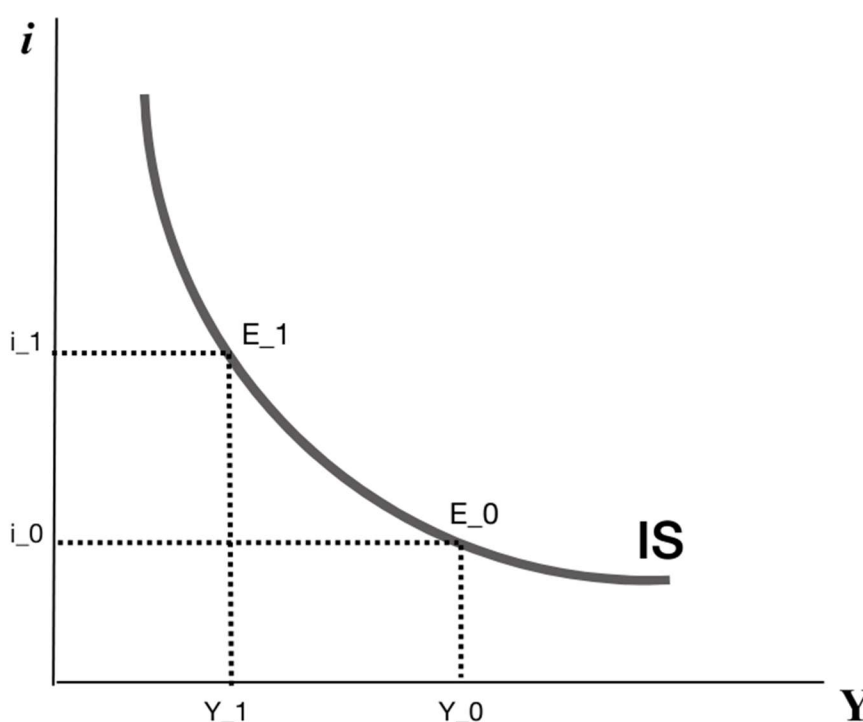


Figure 2: The origin of the IS curve

Figure 2 presents on the x-axis the equilibrium output Y , while on the y-axis is the real interest rate i . It can easily be seen that an increase in i leads to a decrease in Y ; if market equilibrium is initially at the point E_0 , and thereafter an increase in the interest rate occurs, then the new equilibrium point that will be generated will be represented by E_1 , that is, at the intersection of the new real interest rate and the new level of output. The latter is thus a decreasing function of the interest rate.

1.4. The LM curve

The LM curve represents the set of output and interest rate combinations for which the financial market is in equilibrium. For this to happen, the real demand for money (that is money in terms of the goods that can be purchased) must equal the real money supply (i.e., the stock of money in terms of goods). The equilibrium between money supply and money demand is given by the following equation:

$$M/P = \epsilon YL(i)$$

The left side represents money supply, while the right side depicts money demand, which is formed by real income Y (i.e., income in terms of goods that can be purchased) as a function of the interest rate i .

The variables described above are all exogenous except for the interest rate. Prices are exogenous because due to the short-run assumption, while money is exogenous because it is determined by the monetary policy authority. Real income is exogenous to the money sector because it is defined in the real sector. Finally, the interest rate is considered endogenous because its primary function is to incentivize individuals to hold an amount of money equivalent to the real money supply: this equilibrium is referred to as the LM curve.

In order to better observe the relationship that exists between output (Y) and the interest rate (i), it is useful to analyse the Figure constructed below:

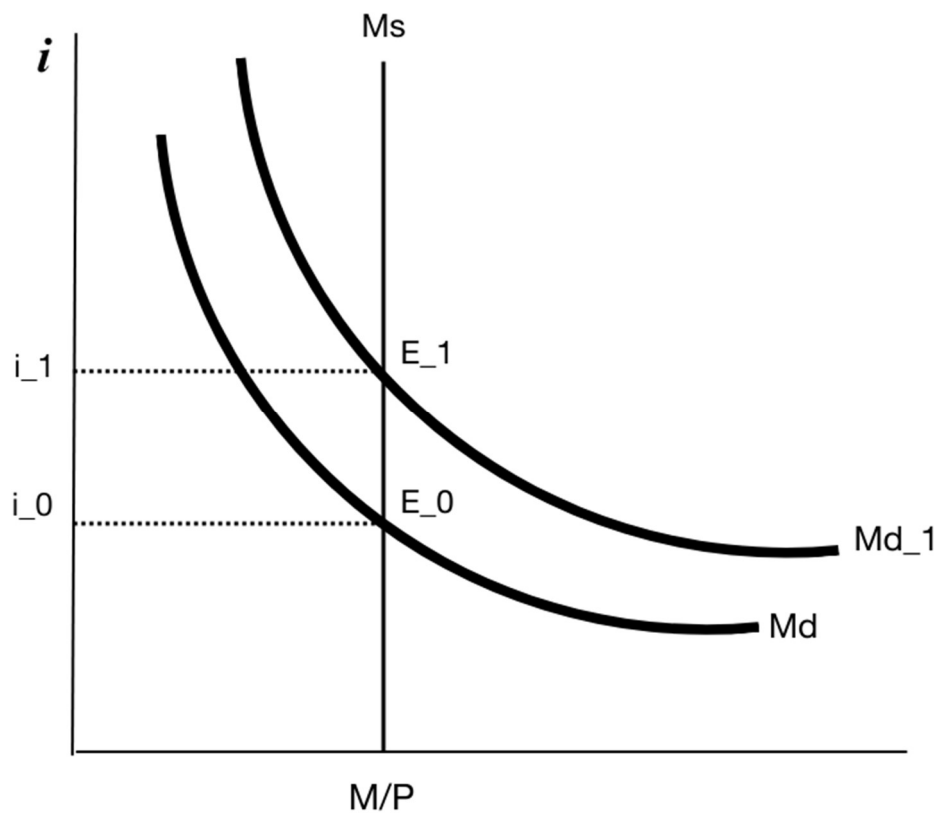


Figure 3: Relationship between money demand (M_d) and the interest rate (i)

As figure 3 shows, real money is placed on the x-axis, while the y-axis measures the interest rate. The real money supply (denoted M_s) is represented by the vertical line whose origin is located at the meeting point (M/P) between the same vertical line and the horizontal X-axis. It always applies that for a given level of income Y , the real demand for money is a decreasing function of the interest rate. It is therefore negatively skewed and within the graph is denoted by the term M_d . Equilibrium is found at the intersection point E_0 , at which money supply meets, and thus equals, money demand and where the interest rate is equal to i_0 .

To highlight the relationship between Y and i we assume an increase in income from Y_0 to Y_1 . This increase leads individuals to increase their demand for money for each level of the interest rate, generating an upward shift in the M_d curve to M_{d_1} . This results in a new equilibrium point at E_1 . The interest rate also rises until it reaches r_1 . All this occurs because, following an increase in income corresponds, as previously observed, to a growth in the demand for money, while the money supply remains unchanged since it is decided by the monetary policy authorities.

Consequently, in order for the financial market to reach a state of balance, the interest rate needs to rise until the additional income that prompts individuals to hold more money and the higher interest rate that encourages them to hold less money cancel each other out perfectly. Only then can there be a harmonious match between the new demand for money and the initial supply of money.

From the graph just analysed, the LM curve can now be derived. Looking at Figure 4 placed below, it is possible, by replacing real money M/P with real income Y on the x-axis, to reconstruct the same equilibrium points (E_0 and E_1) found in the previous Figure:

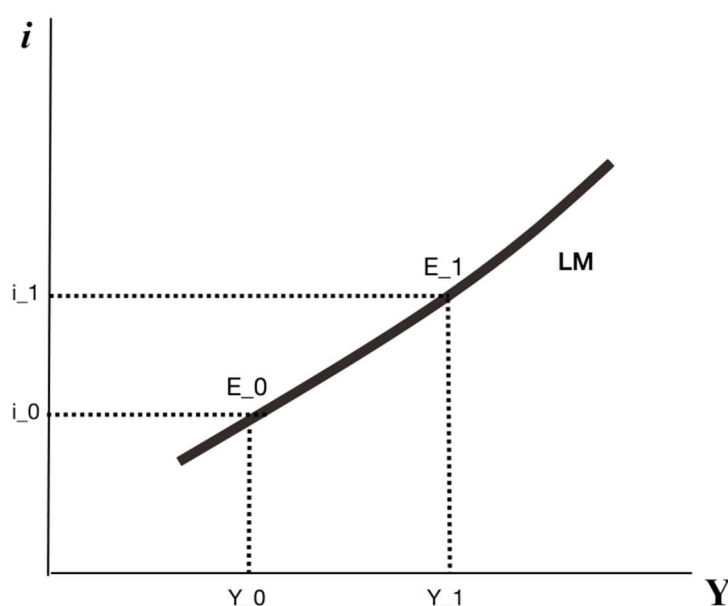


Figure 4: The origin of the LM curve

Equilibrium within financial markets means that the greater the level of output, the greater the demand for money, and thus the higher the equilibrium interest rate. This relationship then forms the LM curve, which is positively sloped.

1.5. The IS-LM Equilibrium

The IS curve is derived from equilibrium in the goods market. The LM curve is derived from the equilibrium in the financial markets. Therefore, to achieve equilibrium in our economy, which is composed of both the goods market and financial markets, both IS and LM must hold simultaneously.

$$\text{IS: } Y = C(Y-T) + I(Y,i) + G$$

$$\text{LM: } i = \bar{i}$$

Together, these two relationships determine the output. Figure 5 shows the IS curve and the LM curve on the same graph. Output or, equivalently, income is measured on the horizontal axis. Interest rate is measured on the vertical axis.

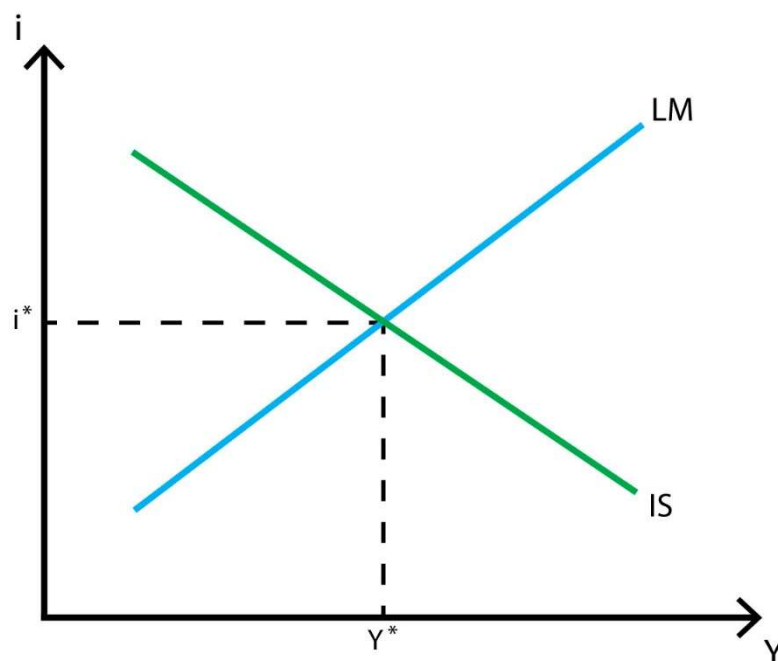


Figure 5: IS-LM equilibrium

Each point on the IS curve (which is negatively sloped) corresponds to a possible equilibrium in the goods market. Each point on the LM curve (which is positively sloped) corresponds to a possible equilibrium in financial markets. Only at the intersection the two equilibrium conditions are satisfied in both markets. This means that the intersection - with the corresponding levels of output, Y , and interest rate - corresponds to general equilibrium, that is the point at which there is equilibrium in both the goods market and the financial markets.

1.6. The IS-LM model applied to monetary policy

Since this dissertation focuses on the effects of monetary policy, this section will only treat the IS-LM model applied to monetary policy and will leave out the implications of fiscal policies.

A monetary expansion occurs when the money supply grows, while a contraction occurs when the money supply is reduced by the central bank. When the central bank implements an expansionary monetary policy, it essentially increases the nominal money supply by buying bonds and injecting liquidity in the market. This increase in the nominal money supply leads to a higher real money supply at a given price level, thus moving the money supply line to the right. Consequently, at a given level of income, the interest rate falls (figure 6A).

$$\uparrow M^s \rightarrow \uparrow M^s/P \rightarrow \downarrow i \rightarrow \uparrow I \rightarrow \uparrow Y$$

The lower interest rate boost the economy by encouraging investments and increasing income. In this case, the LM curve will shift downward, while the IS curve remains the same (figures 6B and 6C). Hence, expansionary policy promotes investments by generating a lower opportunity cost for borrowing, while government debt becomes less onerous.

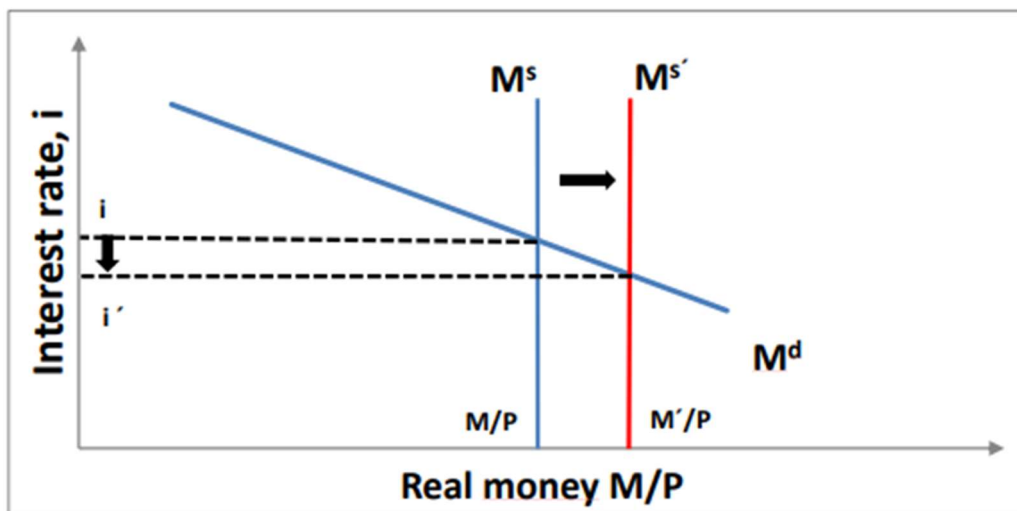


Figure 6A: Effects of a monetary expansion

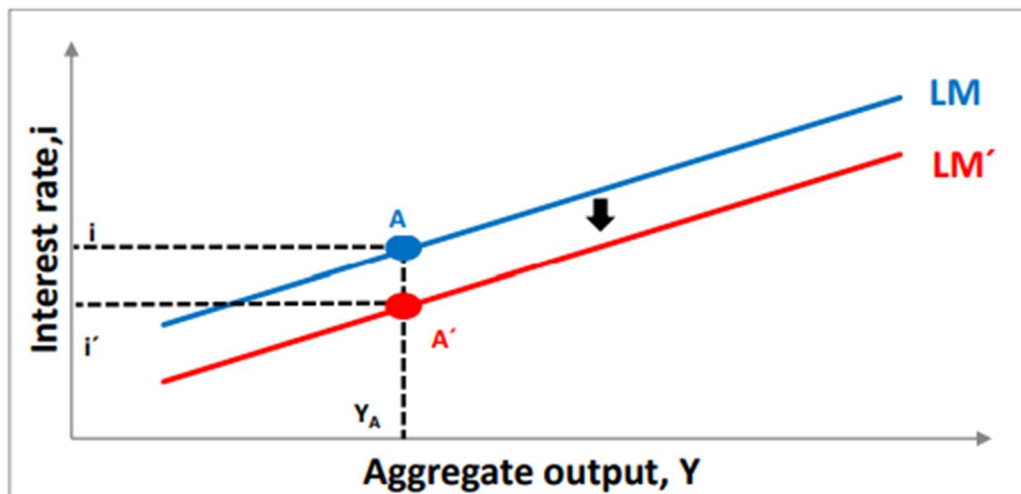


Figure 6B: Effects of a monetary expansion (2)

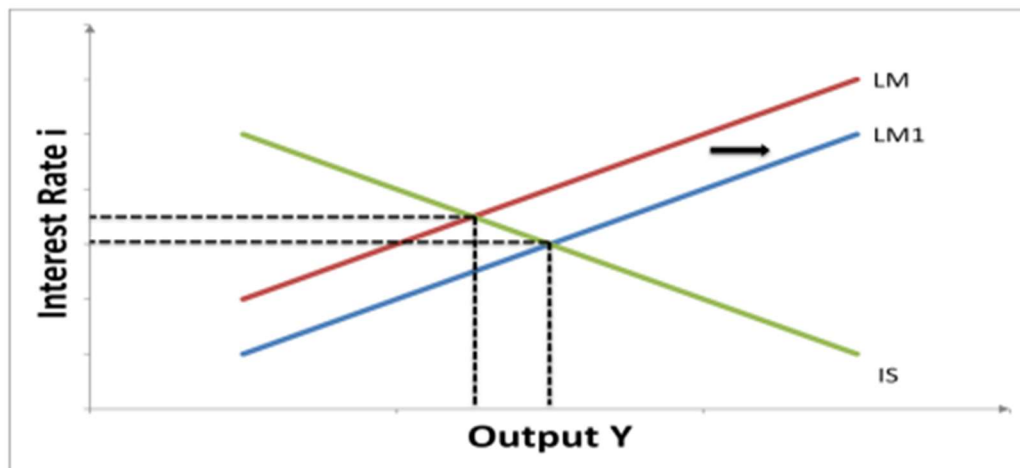


Figure 6C: Effects of an expansionary monetary policy in the IS-LM model

1.7. Equilibrium in the long-run: the AD-AS model

Since this thesis focuses on the long-term effects of monetary policy and its assumed neutrality, it is essential to include the AD-AS model since it's a model that describes the general long-term equilibrium for all the four markets: goods, money, securities, and labour markets.

The tradition typically looks at the IS-LM model as one piece of a more complex aggregate supply and demand (AD-AS) framework. In this model, the level of wages is fixed, and the output price is flexible and adjusts in response to shifts in aggregate demand, caused by changes in exogenous variables.

The IS-LM equilibrium is expressed through the AD curve (aggregate demand), which represents the combinations of price level and output level at which the goods and assets markets are simultaneously in equilibrium.

The general equation for the AD curve is:

$$AD = C + I + G + NX$$

where C is consumption, Y is income and T are taxes. I represents investments, G corresponds to government spending, while NX are net exports.

Until now prices were assumed given and constant. Although sticky in the short run, prices clearly change over time. To determine prices it is necessary, alongside demand, to introduce aggregate supply (AS) into the model. The AS curve originates from the labor market equilibrium that occurs when labour supply and demand are equal. More specifically, the aggregate supply (AS) curve represents the geometric locus of all pairs of Y and P that guarantee equilibrium in the labour market. The curve is characterized by the following equation:

$$P = P^e F(Y, Z) (1+\mu)$$

where μ represents the firms' markup, and P^e are expected prices. The AS curve is positively inclined because higher levels of output Y correspond to higher prices P. This is because an increase in output Y results in an increase in employment, which results in an increase in wages thus coming to reduce the unemployment rate. As a result, the bargaining strength of workers increases which ultimately means that firms will increase their wages to persuade workers to stay. Wages however represent a cost to the firm, so to recover the lost profit given by the higher costs, firms will raise prices.

To demonstrate monetary neutrality in the long run, let's consider the case of an expansionary monetary policy. As seen previously with the IS-LM model, the short-term effects of a monetary policy expansion are the following:

$$\uparrow M^s \rightarrow \uparrow M^s/P \rightarrow \downarrow i \rightarrow \uparrow I \rightarrow \uparrow Y$$

The policy lowers interest rate and boosts investments. In the long run however, prices change, and a process of self-correction takes place. First, as shown in figure 7, the higher money supply pushes the LM curve down, causing higher Y and lower i (LM1).

After some time, prices rise, starting the price-wage spiral that increases salaries. This price increase lowers the M^s/P , causing the LM to move up until it reaches the initial point $LM=LM4$.

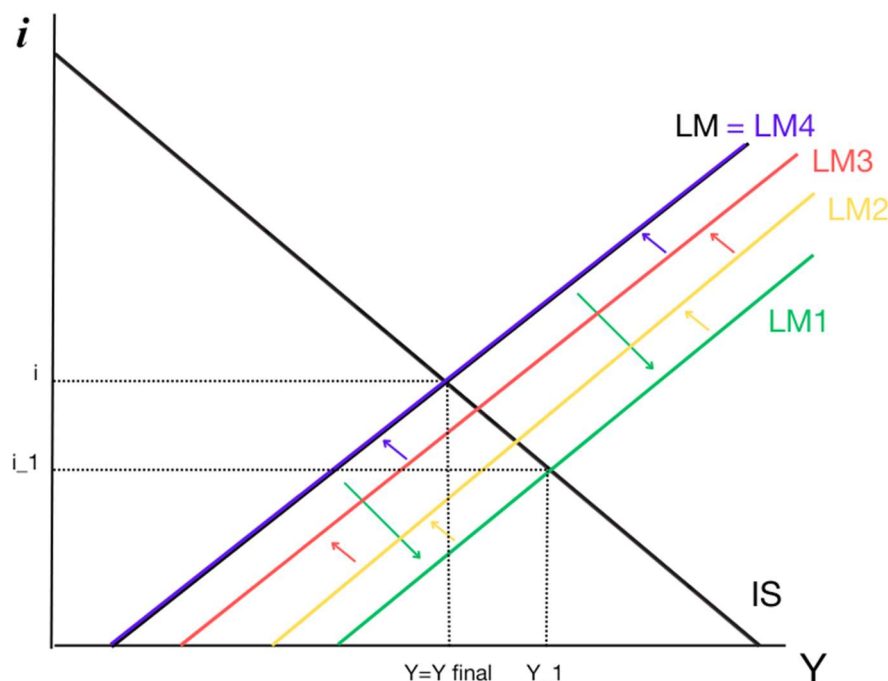


Figure 7: IS-LM adjustment after a monetary expansion

To observe the final outcome, let's see what happens through the AD-AS model.

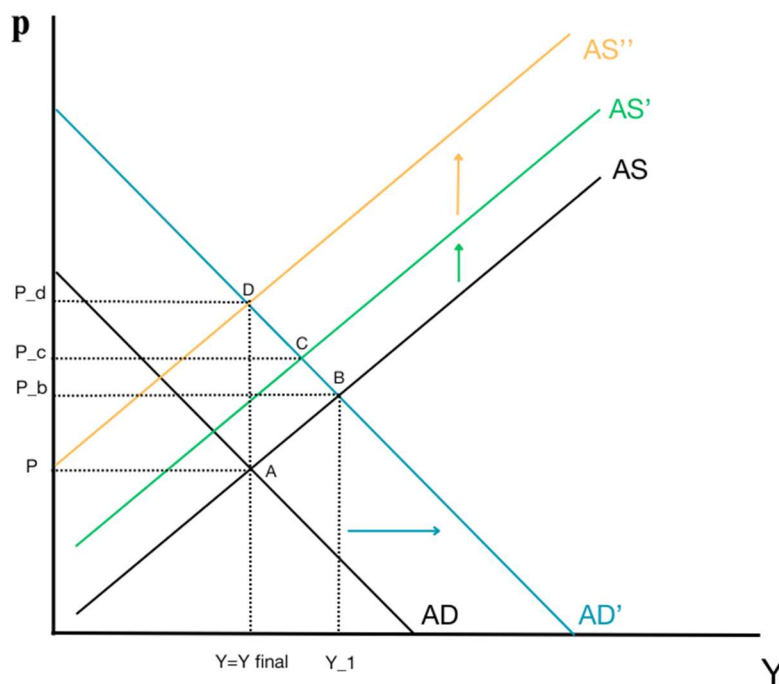


Figure 8: AD-AS adjustment process

As shown in both graphs, the output Y and interest rate (i) go back to their initial position.

The only change pertains to prices, which increase to the D point.

This result symbolizes the concept of long-term monetary policy neutrality: monetary policy influences the values of real variables only in the short run. In the long run, price adjustment makes the real variables return to the natural equilibrium. This concept will be explained further in the next section, as it is the main topic challenged by recent literature.

1.8. Monetary policy neutrality

The concept of monetary policy neutrality dates back to classical economists like David Hume and John Stuart Mill. In his essay "Of Money" (1752), Hume argued that altering the money supply would only impact nominal prices, not real economic output. He famously stated that "If the coin be locked up in chests, it is the same thing with regard to prices as if it were annihilated". This notion formed the basis for the quantity theory of money, which posits that adjustments in the money supply result in proportional shifts in the price level. The quantity theory of money became more well known thanks to the contributions of Irving Fisher and Milton Friedman. Fisher (1911) proposed the equation of exchange, which illustrates how the money supply, velocity of money, price level and volume of transactions are interconnected. Friedman's view suggested that in the long run, changes in the money supply have a neutral effect on the economy, suggesting that central banks should give priority to price stability by regulating the money supply.

In the field of economics, the theory of money neutrality implies that changes in the amount of money impact only nominal variables like prices, wages, and exchange rates without affecting real ones such as GDP, employment, and consumption. This idea is significant in economics, and it is closely related to what's known as the classical dichotomy. If money is neutral, it means that a central bank cannot influence the economy (like employment, GDP or investment) by printing more banknotes. Any increase in the money supply would be offset by an increase in prices and wages. Although many economists consider money neutrality to be an approximation for long term economic patterns, it's important to emphasize that in the short-term changes in money supply can actually affect GDP. This perspective is supported by the notion that prices and wages exhibit a certain level of rigidity, meaning they do not adjust instantly following a monetary alteration. Even if the effect won't hold in the long term, an increase in the money supply can temporarily boost output and employment. For this reason, recognizing the non-neutrality in the short run is crucial for central banks to effectively address economic fluctuations.

Monetary neutrality has a few important implications. The main idea is that changes in the money supply over time primarily affect variations in the general price level. This underscores the pivotal role central banks play in the regulation of inflation and the preservation of price stability. When monetary authorities overly enhance the money supply, it can result in price inflation, eroding the purchasing strength of goods and services. Conversely, a reduction in the money in circulation can lead to deflation, which can adversely affect the economy.

The concept of monetary policy neutrality is an important factor in economic policy choices. Inflation targeting, which is used by many central banks worldwide to stabilize inflation expectations and keep prices from becoming turbulent, is in fact grounded in the idea that long-run monetary policy neutrality holds.

However, there have been several recent papers that have posed challenges to the concept of monetary policy neutrality, as highlighted by the research conducted by Jordà et. al. (2023), Ma and Zimmerman (2023), and Fornaro and Wolf (2022). The upcoming chapter will provide a comprehensive overview of these research studies.

CHAPTER 2

This chapter aims at providing a concise review of the emerging literature that challenges monetary long-term neutrality led by Fornaro and Wolf (2023), Ma and Zimmerman (2023) and Jordà, Singh and Taylor (2023).

2.1. FORNARO & WOLF (2023)

The paper by Luca Fornaro and Martin Wolf (2023) takes a step further into the analysis of the relationship between monetary policy and innovation. Specifically, the authors build a framework that connects monetary policy to companies' adoption of automation technologies, as nowadays technical progress often manifests itself as the implementation of automation. The innovative characteristic of this model is that it suggests that monetary policy doesn't just influence traditional economic variables, but it also affects how businesses make decisions regarding their use of technology for production, that is the mix of labour and capital they choose to employ. In other words, according to the model, monetary policy influences the relative attractiveness of labour and capital for firms, which endogenously decide on their combination of production.

The distribution of tasks between capital and labour is contingent upon the comparison of capital expenses to wages. The cost of capital is determined by the interest rate, which is established through monetary policy. The logic is the following: a monetary policy tightening leads to an increase of the interest rate, and as a result the cost of capital for firms goes up. This higher cost of capital makes labour become relatively cheaper than capital and may therefore motivate firms to shift their production methods from those that rely heavily on capital to those that rely more on labour, thus initiating a process of de-automatization. When this happens, a monetary policy tightening decreases labour productivity. On the other hand, a more expansionary monetary policy may encourage firms to adopt automation technologies extensively which in turn boosts productivity. The relationship between monetary policy, firms' automation decisions and labour productivity is known in academic literature as the "*automation effect of monetary policy*". Consequently, fluctuations in interest rates caused by monetary policy can potentially impact firms' adoption of automation technologies.

The existence of this automation effect suggests that the macroeconomic effects of monetary policy interventions may differ from those predicted by conventional models and may therefore lead to additional consequences.

Going into the specifics of the model, the authors describe labor productivity with the following formula:

$$\frac{Y}{L} = \underbrace{\frac{\gamma^l}{1-J^*}}_{\text{automation}} \underbrace{\left(\frac{\gamma^k}{r+\delta} \right)^{\frac{J^*}{1-J^*}}}_{\text{capital deepening}}.$$

Note: (γ^l) is return on labour; (J) represents the adoption of automation technologies by firms; (γ^k) indicates return on capital; (r) is the interest rate and (δ) measures the depreciation of the rate of capital.

This formula demonstrates that monetary policy has an impact on labour productivity through two distinct pathways. First, there is the typical *capital deepening effect*. Capital deepening refers to increasing the proportion of capital stock relative to the number of labour hours worked. Changes in this ratio are closely linked to variations in labour productivity, assuming all other factors remain constant. Particularly, when there is an increase in capital per hour (that is, capital deepening), a boost in labour productivity takes place. A lower interest rate, for instance, encourages businesses to build up capital and invest in automation, consequently increasing labour productivity.

As a second component the authors introduce the *automation effect*, which adds a new dimension to consider. A decrease in the interest rate can result in a higher number of tasks being carried out by capital, as it becomes less expensive. When this phenomenon occurs, the beneficial effect of a decrease in the interest rate on productivity is amplified.

On the other hand, in line with the concept of capital deepening, keeping the allocation of tasks between capital and labour consistent, a lower interest rate encourages firms to rely more on those tasks that involve using capital.

According to the formula, a monetary tightening can reduce labour productivity because it makes capital more expensive and the use of labour more attractive. For this reason, it may happen that firms demand more labour despite a decrease in demand for their goods. This differs from the New Keynesian model, which usually suggests that tightening policy leads to reduced employment due to less demand for goods.

Considering this viewpoint, it is evident that adjustments in monetary policy can lead to unforeseen consequences in the economy. To illustrate, when monetary measures are persistently tightened, it can potentially hinder the adoption of automation technology by businesses and impact the productivity of their workforce in the long run, despite initially showing a brief positive effect on inflation and employment. Similar conclusions are drawn

by another paper by Moran and Queralto (2018), with slightly different mechanisms. Their paper investigates the relationship between monetary policy and the dynamics of total factor productivity (TFP) using a New Keynesian model that incorporates TFP as an endogenous variable influenced by technological innovation and adoption. The research particularly shows how monetary policy in the model influences medium-term oscillations in TFP through changing companies' incentives to innovate and execute these advances in production. To this regard, Fornaro and Wolf (2021) suggest that higher interest rates stifle innovation and limited potential growth by increasing the cost of capital and suppressing expected demand.

Moreover, differently from the first effect, the automation effect is non-linear because it is active only when movements in the interest rate affect firms' adoption of automation technologies. Specifically, the automation effect of monetary policy only applies when firms have not yet adopted a backlog of automation technologies. This intriguing trait has some unexpected ramifications for how the labour market is affected by monetary policy. To fully comprehend the impact of monetary policy on the job market, it's helpful to explore how companies' demand for labour fluctuates when the steady state interest rate, also known as the labour demand curve, undergoes changes. The demand for labour by businesses is influenced by two main factors: the overall demand for their goods or services and their labour efficiency. When there are alterations in interest rates, it affects both spending and investment within the economy.

As seen previously, a decrease in interest rates leads to an increase in labour productivity through the effects of capital deepening and automation. However, if the overall demand for goods and services remains unchanged, the higher labour productivity may lead to a decrease in firms demand for labour. The authors of this study delve into the interaction between aggregate demand and productivity's impact on labour demand, highlighting that they can potentially counterbalance each other.

Traditional economic models usually focus on the dominance of the aggregate demand effect, which results in a negative correlation between interest rates and labour demand. However, when we take into consideration firms' decisions on automation levels – where they determine how much automation is used – the influence of automation can be substantial enough to reverse this relationship. In order to understand when this is the case, it's necessary to look at the labour demand curve.

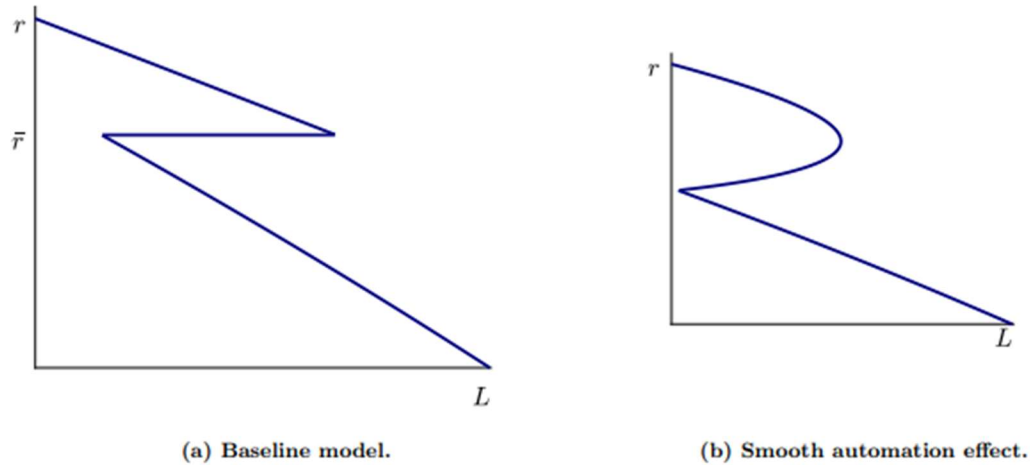


figure 9: The labour demand curve (Fornaro and Wolf, 2023)

The labour demand curve shown in figure 9 illustrates how labour demand (L) and interest rate (r) are linked. $\bar{r}$ represents the difference between the return on capital and the depreciation rate of capital. Three parts make up the curve:

- Downward Slope ($r > \bar{r}$): capital is relatively more expensive compared to labour, so businesses choose to implement more labour-intensive production techniques. Therefore, the levels of automation technologies are low and typical effects of aggregate demand and capital deepening prevail. Put simply, increased labour demand results from a decline in interest rates.
- Flat Segment ($r = \bar{r}$): Since capital is as expensive as labour, firms may replace labour with capital or vice versa according to their profit maximization.
- Downward Slope ($r < \bar{r}$): Businesses employ high levels of automation technology because capital is cheaper compared to labour.

The threshold $\bar{r}$ is crucial in this regard, as changes in interest rates can strongly influence decisions about automation and labour demand. Beyond the threshold, the costs of capital rise and the level of automation remains minimal. In contrast, below $\bar{r}$, capital becomes more affordable, and automation is much more prevalent. Around this threshold, the impact of automation on the economy becomes particularly pronounced, overshadowing the typical influence of aggregate demand.

Considering a case of interest rate decrease: A lower interest rate, on the one hand, encourages aggregate demand, indicating increased labour demand and employment. On the other hand, enterprises are compelled to convert from low to high automation technology if the interest rate falls from above to below the threshold. As a result, there is a noticeable rise in labour productivity and a consequent decline in the need for labour among businesses. In some cases, the automation effect is so potent that, contrary to common knowledge, a decrease in the policy rate may actually have a negative impact on labour demand and employment.

But what are the implications of this effect? A first consequence of the automation effect is that the impact of monetary interventions on employment may not follow the traditional pattern. According to the conventional viewpoint presented by the New Keynesian model, tightening monetary policies lead to a decrease in employment. This is because tighter policies reduce demand for both consumption and investment, causing companies to react by laying off employees. To this regard, Fornaro and Wolf's framework introduces the idea that monetary tightening can also decrease labour productivity through automation. This means that, under certain circumstances, the relationship between the policy rate and firms' labour demand may not follow a straightforward pattern, potentially resulting in a non-monotonic labour demand curve.

A consequence of the non-monotonic labour demand curve is that the economy may have multiple ways to achieve full employment. In fact, according to the authors, there might be multiple stable steady states that allow full employment, each one linked with a different natural rate (see Figure 10).

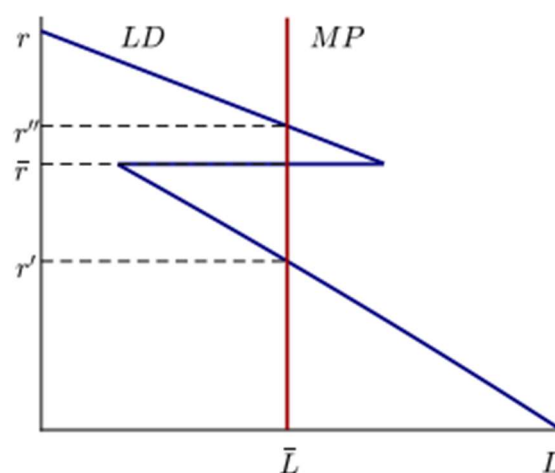


Figure 10: Multiple full employment steady states (Fornaro and Wolf, 2023). *Note:* (LD) represents firms' labor demand; (MP) is the monetary policy stance; ($\bar{L}$) denotes the full employment steady state.

Assuming that monetary policy ensures that the economy operates at full employment in a steady state - meaning that the central bank sets the interest rate at a level that ensures companies' demand for labour matches the full employment level - there are three different scenarios.

In the first case the interest rate is high enough ($r = r'' > \bar{r}$) that businesses employ capital solely to execute tasks that strictly require it. In this state of equilibrium, the demand is so minimal that companies can fulfil it without automating much of their production technologies. However, to maintain full employment, they choose to hire all available workers despite the low demand for their products by reducing wages.

The middle one is characterized by an interior equilibrium ($r = \bar{r}$). In this state, automation is only partially achieved. Although aggregate demand is strong enough to push firms to replace labour with capital for some production activities, it is still not high enough to fully automate production.

In the third scenario the interest rate is low ($r = r' < \bar{r}$) and firms embrace automation in their production processes. Consequently, increased automation leads to higher labour productivity and wages as well. Full employment is achieved through sustained robust demand that prompts companies to continue hiring workers.

It's worth to note that the effect of monetary interventions on the economy can differ depending on the time period being examined, as indicated by the model by Fornaro and Wolf (2023). When the central bank implements a continuous rise in the actual interest rate, it initially triggers an expected reaction with a decline in employment. This occurs because businesses require time to invest and make adjustments to their use of automation in their production processes. However, in the long term, companies may react to stricter monetary policies by reducing their reliance on automation in production. In this situation, a restrictive monetary policy leads to reduced levels of automation and labour productivity in the long run. It is even plausible that tightening monetary policy could lead to a transition from high automation to lower levels of automation that endure over an extended period. In such instances, a period of tight monetary policy is followed by a lasting decline in productivity. Further, over time, changes may occur in how inflation reacts to monetary tightening. In the short term, heightened unemployment tends to exert a dampening effect on both wage and price inflation. The drop in labour productivity brought on by less automation, however, brings an inflationary component over the long run. Therefore, a prolonged tightening of the monetary policy might start a cycle of falling and then rising inflation. On the other hand, a monetary policy expansion that follows a different pattern can initially cause an overheated

labour market and short-term inflation. As a result, more automation use and higher labour productivity may operate as a counterforce, gradually easing inflationary pressures.

Although monetary actions may persuade businesses to alter how they use automation technologies, this does not imply that all monetary interventions will have the same result. In fact, the macroeconomic effects of monetary policy often exhibit time, magnitude, and state dependence. The concept of time plays a crucial role in the adaptation of production technologies within firms. To illustrate, the integration of more robotic systems into a manufacturing facility is not a task that can be accomplished in just a quarter or two. When it comes to converting investment into productive capital, the model assumes that it only takes one period. But it's important to remember that producers of capital face significant adjustment costs. As a result, in the short term, monetary interventions have a conventional impact on the economy. It is only in the long term, once the capital stock has undergone adjustments, that a monetary intervention might influence the adoption of automation technologies and labour productivity. Another relevant highlight is that the adoption of automation by businesses is only likely to be influenced by consistent monetary interventions. This is because businesses typically base their investment choices on medium-term interest rates and are hesitant to respond to transient changes in monetary conditions. In other words, only persistent monetary interventions have an impact on firms' adoption of automation because they base investment decisions on medium-term interest rates.

Indeed, the concept of time ties in with the magnitude of the interventions. In essence, it is unlikely that minor monetary fluctuations will have a significant effect on the technological practices used by businesses. The adoption of automation technologies by businesses can only be significantly changed by major interventions. Only until there is a large enough intervention to drive the economy into the area of partial automation do the effects of monetary tightening on automation and labour productivity become apparent. On the other hand, the economy's response would remain completely traditional in the case of a slight increase in the policy rate.

Ultimately, the impact of monetary interventions relies on the current state of the economy, specifically its proximity to the forefront of automation. For example, if businesses have already maximized the utilization of existing automation technologies, expansionary monetary policies will not result in further automation in production. The positive effects of such policies are only evident when there is a backlog of untapped automation technologies, enabling an expansionary policy to stimulate their adoption. On the other hand, once automation has reached its minimum level, a monetary tightening will cease to influence it.

The framework suggested by Fornaro and Wolf (2021) suggests that changes in macroeconomic conditions may pose unconventional challenges for monetary policy. In prolonged periods of subdued economic activity, the central bank may encounter a dilemma where it must choose between preserving jobs or promoting automation.

The theory proposes that the impact of monetary interventions may exceed the usual targets of employment and inflation. Indeed, because monetary policy has the potential to influence how businesses invest in automation, central banks might need to consider this effect when making decisions about monetary policy.

2.2. MA & ZIMMERMAN (2023)

The argument that monetary contractions negatively impact investment in innovation, leading to hindered growth, is supported by another study conducted by Yueran Ma from the University of Chicago and Kaspar Zimmermann from the Frankfurt School of Finance & Management (2023).

The authors pieced together both casual observations and academic literature to investigate how monetary policy influences innovation. Observations indicate that changes in the interest environment during the past decade have had noticeable impacts on the funding of innovation, including venture capital investment. Indeed, startups experienced rapid expansion when interest rates were low, but faced significant challenges when interest rates began to rise in early 2022, resulting in a sharp decline in venture funding (National Venture Capital Association, 2023). It's worth noting that the decline is visible across all major industries, and not just those associated with speculative booms like cryptocurrency.

According to Ma and Zimmerman, both demand conditions and financial conditions play a role in the transmission of monetary policy to innovation activities. By reducing demand through tightening policy, the profitability of developing new products and the incentives to innovate can decrease (Benigno and Fornaro, 2018). Particularly, patent filings drop following a reduction in monetary policy, whether the companies involved are public or private, and regardless of their size. Additionally, the data shows a greater decline in R&D work and patent filings among cyclical industries.

Secondly, the authors note that the implementation of tighter monetary policy can impact financial conditions by decreasing the willingness to take risks. This part of the monetary transmission mechanism has been recently referred to as the risk-taking channel and relates to how changes in monetary policy rates affect either risk perceptions or risk-tolerance (Altunbas et al., 2014).

To investigate, the authors make use of a variety of metrics of innovation: in addition to considering the total investment in intellectual property, which includes research and development (R&D) spending, as reported in the national accounts and by public companies, authors also consider measures based on venture capital (VC) investment and the number of patent filings. Venture capital is renowned for investing in innovative firms; prior research also indicates that a dollar of venture capital is approximately three times more effective in stimulating patent production than a dollar of traditional research and development (R&D) (Kortum and Lerner, 2000).

The authors utilize the conventional method of analysing local projection impulse responses to shocks in monetary policy. Monetary policy shocks capture variations in the Federal Funds rate that cannot be explained by the prevailing economic conditions, with the purpose of isolating the influence of monetary policy on future economic activities. Their baseline studies employ the Romer and Romer (2004) shocks from 1969 to 2007.

The research, presented at the Jackson Hole conference, found that when interest rates increase by one percentage point over a three-year period, a noticeable decline in spending on research and development takes place, with approximately a 1 to 3 percent decrease.

Additionally, there is a decrease of about 25 percent in venture capital investment and a 9 percent decline in patenting and innovation. It is interesting to note that patenting in important technologies appears to be more affected than general patenting, which experiences only around half as much decline (see figure 11). To this regard, Zimmerman and Ma also discovered that emerging technologies such as cloud computing and electric vehicles are particularly susceptible to fluctuations in interest rates.

Furthermore, the VC investment declines for both early stage and late stage startups after tightening monetary policy. This reduced funding for early stage startups might be due to a decreased interest in investing in risky ventures since they are still in the product development phase and may not have products ready for the market immediately.

Authors also make use of the *aggregate innovation index* built by Kogan et al. (2017). The innovation index experiences a decrease of up to 9 percent within 2 to 3 years after the shock. According to the findings in Kogan et al. (2017), a reduction of 9 percent in the innovation index for more than a year can result in a 1 percent decrease in output and a 0.5 percent decline in TFP 5 years later. Estimates of the societal returns to innovation expenditure agree with these values. These numbers are quite significant in both economic and social terms: Jones and Summers (2020) indicate that one dollar spent on innovation yields around ten dollars in societal return.

These results can induce some valuable insights. Research and development (R&D) spending makes up about 2.5 percent of the Gross Domestic Product (GDP), while venture capital (VC) investment is approximately 0.75 percent of GDP. If R&D spending decreases by 2 percent and VC investment falls by 25 percent, this would lead to a 2 percent decline in overall production. In other words, the impact of innovation on the economy's productive capacity is significant, as it yields high returns. Therefore, fluctuations in innovation activities may result more crucial than changes in traditional investments in physical assets.

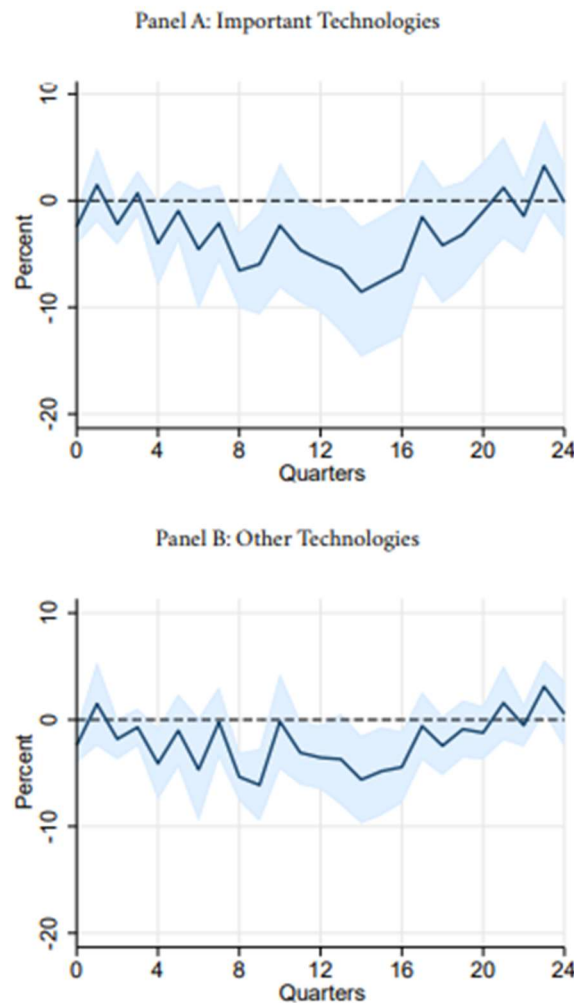


Figure 11: Impulse Response of Patent Filings in Important Technologies to Monetary Policy Shock
(Ma and Zimmerman, 2023)

Note: Panel A shows the impulse response of patent filings associated with the important technologies to a 100 basis point Romer and Romer (2004) monetary policy shock. Panel B shows the impulse response of patent filings associated with other technologies.

Nevertheless, it is healthy to question whether these episodes represent drops of real socially valuable innovation, or corrections of bubbles and excessive investment. About that, economic research generally suggests that innovation is not fully supplied due to significant positive externalities. On the other hand, there have been instances where companies without viable businesses were able to secure ample funding due to the inflated valuations during the dotcom boom.

While numbers imply that monetary tightening affects innovation activity, fluctuations may indeed provide benefits by filtering weak firms (Schumpeter, 1942). A business study by Hamano and Zanetti (2022) emphasizes this point of view by highlighting the allocative function of monetary policy, which filters unproductive firms. This position is perhaps reinforced by the observation that in the last 150 years, there have been many technological advancements that emerged and thrived despite difficult times. For example, computerization occurred during a time when the U.S. Economy was grappling with high inflation and high interest rates due to the oil crisis. Going backwards, widespread electrification occurred even during the crises of 1893 and 1907 (Jovanovic and Rousseau, 2005). However, these technologies were perhaps so revolutionary that they behaved differently when encountering economic difficulties compared to “normal” - but still positive - innovations. For this reason, Ma and Zimmerman (2023) interpret their evidence by stating that monetary policy can affect “evolutionary” innovation activities rather than “revolutionary” ones.

A number of concerns may arise as a result of the connection between monetary policy and innovation. Should monetary policy be more accommodating on average, considering the undersupply of innovation caused by high social externalities? Recent studies indicate that depending on the nature of shocks, optimal policy may involve implementing inflation targeting outside the zero lower bound or increasing inflation above the target level when there is a shortfall in subsidies for innovation that address externalities (Ma and Zimmerman, 2023; Garga and Singh, 2021; Queralto, 2022). Furthermore, should monetary policy be more countercyclical, and more responsive to production in particular? A study suggests that countercyclical stabilization becomes particularly crucial in situations when cyclical variations hinder innovation and growth (Aghion et al., 2012). In this regard, the question arises as to whether monetary policy should be made more countercyclical and responsive to output.

Alternatively, the authors point out the possibility of implementing alternative policies that could address fluctuations in innovation activities. Indeed, there is some argument regarding whether alternative instruments can assist and regulate innovative activities, so that monetary policy can have a simpler focus instead of balancing multiple issues with one instrument.

More specifically, recent research has shed light on macroprudential policy's capacity to target financial stability while allowing monetary policy to focus on macroeconomic stability. Similarly, in the domain of innovative activities, it is important to investigate if alternative tools can offer assistance and stability, such as grants and subsidies.

Furthermore, recent studies show that fiscal measures have the capacity to lift the economy out of stagnation, as proven by Benigno and Fornaro's study in 2018. These measures can also encourage corporate investment and reduce supply-side restrictions, which is especially important when monetary policy tightens during periods of disinflation, as Fornaro and Wolf (2023) suggested. Relaxing supply-side limitations may result in lower marginal costs and less inflationary pressures.

It is unclear if concerns of innovation can be effectively handled by alternative approaches, enabling monetary policy to function independently without regard for its effects on innovation. Future study efforts may provide further information on this subject.

In conclusion, Ma and Zimmerman (2023) show that monetary policy can impact innovation activities by altering aggregate demand and thus the profitability of innovation, as well as by shifting the conditions in the financial market. Their findings indicate that monetary policy might influence the long-term productive capacity of the economy, in addition to the widely acknowledged short-term effects.

Nevertheless, as the researchers note, these findings don't directly imply that a more accommodating monetary policy is desirable. Indeed, it is well acknowledged that efforts to perpetually stimulate the economy by monetary easing can be unsuccessful or even destructive (Friedman, 1968; Lucas, 1976). For this reason, further research on the impact of monetary policies may be needed.

2.3. JORDÀ, SINGH and TAYLOR (2023)

Jordà, Singh and Taylor (2023) discuss the influence of monetary policy on an economy's long-run productive capacity and challenge the assumption of monetary long-run neutrality. Specifically, they perform long-run cross-country analyses to identify exogenous monetary policy fluctuations and measure long-run output effects. To investigate the effects and construct their thesis, the authors build their case on three key components.

First, they begin by identifying exogenous monetary policy fluctuations to obtain an accurate estimate of monetary effects. The starting argument stems from the trilemma of international finance, which provides a theoretical explanation of exogenous fluctuations in interest rates: in simple terms, when a nation pegs its currency to a base currency while allowing free cross-border capital flow, it effectively loses the ability to regulate its own local interest rate,

therefore creating a correlation between home and base interest rates. Theoretically, strict interest parity implies that rates are perfectly correlated in frictionless situations. Obviously, this association isn't exactly perfect in practice. However, a non-zero interest rate connection between a home economy and the base economy to which it pegs its exchange rate is considered sufficient by the authors for identification using instrumental variables even under soft pegs, frictions, or imperfect arbitrage. Indeed, as long as base rates are solely based on the circumstances of the base nation, they might be a possible source of exogenous variance in home rates. Authors establish this identification strategy on a fundamental New Keynesian small open economy model (Fornaro and Romei, 2019). Specifically, they derive analytical results to formally demonstrate how this approach yields the exact monetary policy impulse response function of interest, with or without the existence of spillover effects.

Second, because the authors are interested in long-run consequences, they employ a panel of countries monitored over as long a period as possible in order to increase the data span and, therefore, the statistical strength of their findings. More specifically, the researchers make use of two macro-history databases that cover a period of 125 years and include data from 17 advanced economies: the first one includes key macroeconomic series like output, interest rates, inflation, credit, and others (Jordà, Schularick, and Taylor, 2017). The second contains observations on investment machines and buildings, number of employees and hours worked (Bergeaud, Cetto, and Lecat, 2016). With these variables, they calculate metrics for total factor productivity (TFP), which includes adjustments for utilization. They then analyse the factors that contribute to changes in output, such as TFP, capital input, and labour input, in order to examine the causes of the hysteresis.

Regarding models, Jordà, Singh and Taylor (2023) recognize that the most common empirical approaches are built to maximize short-term fit, and for this reason they also focus on designing a method that fits longer time spans. To get more precise estimations of the impulse response function (IRF) over longer horizons, the authors apply local projections (Jordà, 2005). They officially demonstrate that local projections (LPs) reliably predict the impulse response at any horizon as long as the truncation lag is set to increase with sample size. Indeed, local projections are in fact semi-parametrically effective in situations where the lag order may be infinite and the truncation lag is permitted to increase with the sample, as recently demonstrated by Xu (2023). As noted in the paper, some of the earlier literature may have been unable to recognise the highly persistent effects due to the usage of other commonly used methods that lack this exact property.

In light of these three elements, Jordà, Singh and Taylor show that monetary policy has a long-lasting impact on the economy's productive capacity (see Figure 12). When there is an

exogenous monetary shock, production falls and doesn't recover to its pre-shock trend for even twelve years. In more detail, a 1 percentage point shock in domestic short-term interest rates has substantial and protracted negative impacts on GDP regardless of the sample employed. The GDP decreases by 4.60 percent during a 12-year period in the entire sample. The restricted post-WW2 sample reveals a similar impact: twelve years after the impact, the decline is 3.94 percent. Capital and TFP are the main drivers of this result and they both follow similar output-related paths. In contrast, the total number of hours worked (including the number of employees and hours per employee) tends to return to the initial trend. Capital accumulation is consistent with traditional, well-recognized short-term patterns. The capital reaction is initially subtle but intensifies over time. However, in contrast to the New Keynesian model (Gali, 2015b), the capital stock remains unrecovered even after a period of 12 years. Likewise, TFP falls gradually rather than abruptly, and also does not recover. In other words, the capital stock and total factor productivity (TFP) exhibit long-lasting effects, while labour does not, and money's impact on the economy lasts longer than conventionally assumed. The results put forth substantial evidence concerning the enduring implications of monetary policy shocks, manifesting signs of hysteresis that extend over a period exceeding ten years.

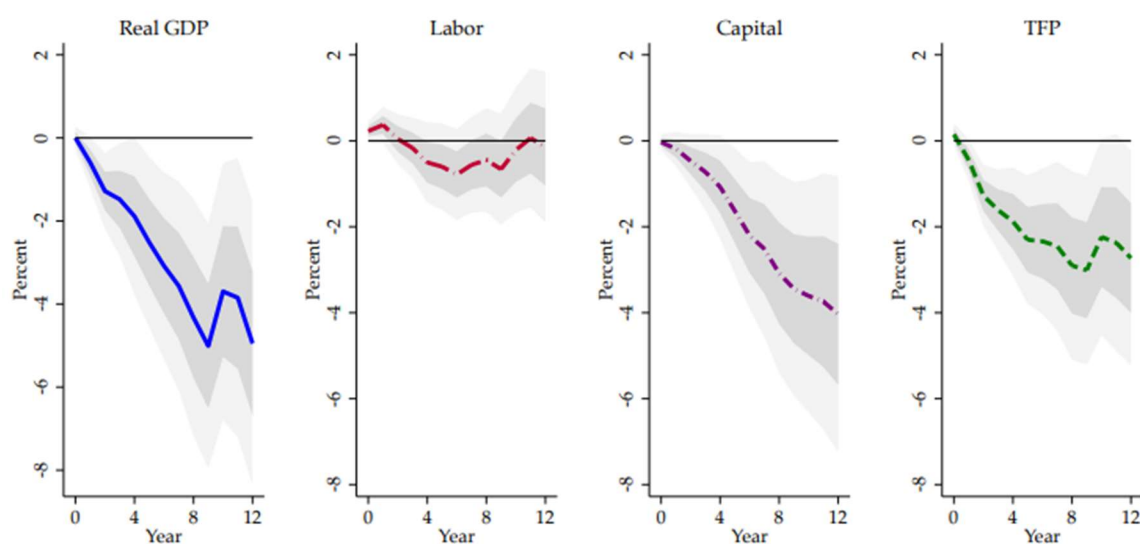


Figure 12: Baseline response to 100 bps shock: Real GDP and Solow decomposition.

Full sample, 1900–2015 (Jordà, Singh and Taylor (2023)).

It's important to highlight that the authors themselves raise doubts about their assumption regarding the symmetric estimation technique. To put it more plainly, can we argue that the central bank has the capability to enhance the economy's potential through accommodative

monetary policies, just as contractionary measures appear to diminish its long-term productive capacity? The response appears to lean towards the negative.

By calculating the response to a 100-bps loosening and tightening shock in domestic short-term interest rate, Jordà, Singh and Taylor (2023) demonstrate that central banks cannot utilize loose policy to manipulate the supply-side of the economy and enhance its long-term capacity. However, tight monetary policy has the potential to decrease the long-term productive capacity of the economy. This asymmetric hysteresis data underlines the importance of the policy implications: While exceptionally tight policy poses substantial downside risks, excessively loose policy fails to deliver notable upside benefits.

In summary, this paper provides an examination of the long-term effects of monetary policy measures. By utilizing a vast dataset and advanced statistical techniques, the study demonstrates that decisions regarding monetary policy can have lasting impacts on economic outcomes. Indeed, monetary policy has long lasting effects that can extend beyond ten years. The main factors behind this outcome are capital and TFP (Total Factor Productivity) growth, whereas the number of hours worked does not seem to have an impact. It is crucial to note that the responses differ when comparing tightening shocks with loosening ones, showing an asymmetrical pattern.

The research underscores the importance for policymakers to consider not only the immediate consequences of their actions but also any potential long-lasting effects, especially in a time when unconventional monetary policies are prevalent.

2.4. Final Considerations

Central banks place significant importance on monetary policy as they strive to uphold economic stability and foster growth. While there is a lot of discussion and analysis regarding its short-term effects, recent studies have raised questions about the long-term neutrality of monetary policy and its lasting impacts.

This chapter delved into the long-term consequences of monetary policy, drawing insights from recent research articles that focus on its effects in the longer run. The study by Jordà, Singh, and Taylor (2023) investigated the relationship between monetary policy and long-run economic growth. They found that monetary policy has strong effects that can last for more than a decade. The driving forces of this result are capital and TFP growth, while hours worked didn't have an impact. What's important to remember from their research is that responses are asymmetric when comparing tightening shocks with loosening ones.

Innovation plays a critical role in driving long-term economic growth and prosperity. The relationship between monetary policy and innovation is explored in the research paper by Ma

and Zimmermann (2023). Specifically, they show that after a significant increase in interest rates by 100 basis points, there is a noticeable decrease of approximately 1 to 3 percent in research and development (R&D) expenditure, as well as a decline of about 25 percent in venture capital (VC) investment over the next 1 to 3 years. Moreover, patenting activities related to critical technologies, along with the overall innovation index based on patents, experience a decline of up to 9 percent over the subsequent 2 to 4 years. The actions taken by monetary policy can have an impact on innovation activities by altering the overall aggregate demand and, as a result, the profitability of innovation. Additionally, it can also affect the conditions within the financial market. The research findings indicate that monetary policy has the potential to influence the long-term productive capacity of the economy, in addition to its well-known immediate effects on economic outcomes.

In their 2022 paper, Luca Fornaro and Martin Wolf focus on the role of monetary policy in the age of automation. Specifically, the authors point out how monetary policy affects firms' decisions on the intensity of use for capital and labour in production. For this reason, monetary policy may have additional effects other than the traditionally known ones, potentially contributing to creating further effects. For instance, monetary tightening may reduce labour productivity due to the automation effect. However, for a given aggregate demand, lower productivity increases firms' labour demand. These effects can therefore offset one another, which ultimately means that the relationship between policy rate and labour demand may be non-monotonic.

Although this chapter provides a brief summary of the novel literature against long-run monetary policy neutrality, the author doesn't directly suggest that monetary policy alone should address all problems mentioned. As Soumaya Keynes mentioned in the Financial Times (2023), it is healthy to question old assumptions from time to time, and acknowledging these recent studies may help central banks recognize the impact of their future policies.

CHAPTER 3

This chapter examines the potential long-term impact of monetary policy shocks on the natural interest rate and other variables using a "proxy-SVAR" à la Plagborg-Møller and Wolf (2021). The analysis will employ a measure of monetary policy that has been adjusted to remove the influence of information shocks, as highlighted in recent macroeconomic research (Cieslak and Schrimpf, 2019; Jarociński and Karadi, 2020; Miranda and Agrippino, 2021). Miranda and Agrippino (2021) provide the instrument at issue, which counts for the exogenous variation of the nominal interest rate filtered from information shocks. The chapter starts by introducing the concept of a structural VAR and the Cholesky identification used in the analysis. Section 3.3. will explain the rationale for using the proxy of monetary policy shocks constructed by Miranda and Agrippino (2021). Finally, the chapter presents an empirical analysis via SVAR models to estimate the long-run effects of monetary policy shocks on the natural rate of interest and other variables.

3.1. VARs

Christopher Sims introduced vector autoregressions (VARs) in 1980 as an alternative to traditional large-scale macroeconometric models when the theoretical and empirical support for these models became increasingly doubtful. VARs provided a straightforward model for understanding complex temporal patterns in multiple time series, and the accompanying statistical toolkit was both intuitive and easily understandable (Stock and Watson, 2001). Unlike a univariate autoregression, which explains a variable's current value using its own lagged values, a VAR is an n -equation, n -variable linear model in which each variable is in turn described by its own lagged values, plus current and past values of the remaining $n - 1$ variables (Kilian and Lütkepohl, 2017). There are three types of VARs: reduced form, recursive, and structural. This paper will focus on the latter, as it is the one used in the empirical study.

A structural VAR uses economic theory to sort out the contemporaneous links among the variables and incorporates it to impose structural constraints on the VAR model (Sims, 1986; Stock and Watson, 2001). In other words, structural VARs necessitate “identifying assumptions” that enable correlations to be interpreted causally. Sims (1986) describes the identification problem as the process of generating economic interpretations behind the correlations. In this sense, economic theory can help provide the “missing equation” by making an assumption on the structure of an economy based on beliefs and then mapping this assumption into an equation involving VAR parameters. This additional equation is known as a restriction, technically an equation that restricts the set of infinite B matrices to one (or few

ones) that are consistent with the assumption (Cesa-Bianchi, n.d.). These identifying assumptions can involve the entire VAR, so that all of the causal links in the model are spelled out, or just a single equation, so that only a specific causal link is identified. This produces instrumental variables that permit the contemporaneous links to be estimated using instrumental variables regression.

A structural VAR of order 1 is given by:

$$x_t = \phi x_{t-1} + B\epsilon_t$$

Where ϕ and B are (2×2) matrices of coefficients, while ϵ_t is a (2×1) vector of unobservable zero-mean white noise processes, that is elements of ϵ_t that are serially uncorrelated and independent of each other. A structural VAR can also be expressed with a matrix form:

$$\begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} = \begin{bmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{bmatrix} \begin{bmatrix} x_{1t-1} \\ x_{2t-1} \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{bmatrix}$$

While structural VARs can answer many interesting questions, their estimation is quite tricky. In Structural Vector Autoregression (SVAR) models, the presence of correlation between error terms is a significant issue. This correlation arises when the unobserved shocks influencing the variables in the model are interrelated. Such interrelatedness can distort the estimation of the model's parameters, misrepresenting the actual economic dynamics being studied. Consequently, it is crucial to address this issue to obtain reliable results. This is precisely where the Cholesky decomposition can be involved in our study (Castelnuovo, 2016).

3.2 Cholesky decomposition

To overcome the correlation of errors, the analysis will use the Cholesky decomposition. The Cholesky decomposition is a mathematical procedure that deals with the problem of correlated errors. It transforms a covariance matrix of the error terms, representing their correlations, into a matrix with zero correlations between different error terms. This transformation is accomplished by multiplying the covariance matrix by a specific lower triangular matrix derived from the Cholesky decomposition (Higham, 1990). The resulting matrix is a diagonal matrix, indicating that the transformed errors are now uncorrelated or

orthogonal. This orthogonality is essential for accurate and unbiased estimation in the SVAR model, as it ensures that the impact of each shock is isolated and not confounded with others. When applying Cholesky decomposition in SVAR models, the order in which variables are introduced into the model is of great importance (Zhang, 2022). This ordering determines the structure of the lower triangular matrix used in the decomposition process. The chosen order reflects assumptions about the immediate or contemporaneous relationships among the variables. For example, if one variable is assumed to affect another but not vice versa contemporaneously, this assumption will be reflected in the ordering. Theoretically sound or empirically validated justifications are required for this ordering since they significantly affect the model's results. The ordering influences how the shocks from one variable are transmitted to others within the model, and consequently, different orderings can lead to varying interpretations of the underlying economic dynamics.

In a SVAR model with Cholesky decomposition the first variable is considered exogenous, i.e. it is not caused by any contemporary element. The lower the variable, the more endogenous it is. The Cholesky decomposition simplifies the interpretation of the structural shocks in a VAR model, because it assigns a causal order to the variables, making it clear which variable each shock affects. This simplifies the interpretation of the shocks and allows for more straightforward analysis.

3.3. PROXY: rationale and construction

At this point, one may rightly question how the ranking is decided. In this regard, Miranda-Agrippino and Ricco (2021) pitch in by offering an exogenous monetary policy proxy, which will serve as the instrumental variable in the analysis. An instrumental variable (IV) is an observed variable that is correlated solely with the shock of interest, and not with other shocks that affect the variable of interest (Plagborg-Møller and Wolf, 2021).

Given that this proxy encompasses some recent economic literature concerning the distinction between monetary policy shocks and information shocks, it is appropriate to clarify how it was constructed and why it will be used.

The dynamic responses to monetary policy shocks can be sensitive to the choice of the instrument, sample, and empirical specification (Coibion, 2012; Ramey 2016). On that note, it is crucial to emphasize that instruments commonly used to identify monetary policy disturbances often combine the actual policy shock with information about the economy's state due to the disclosure of information through the policy action. On this matter, a chunk of literature focuses on this identification problem by targeting the difference between real monetary shocks and information shocks.

While trying to disentangle these two elements, Jarociński and Karadi (2020) documented a remarkable observation about FOMC announcement surprises. The authors refer to financial asset price changes around FOMC monetary policy announcements as “surprises.” This terminology arises because prices only adjust if the announcement catches the markets off guard, assuming that prices reflect expectations. These surprises are typically measured within a half-hour timeframe calibrated from 10 minutes before to 20 minutes after the announcement. This short time frame allows us to interpret the shock as exogenous, since it is improbable that these surprises are caused by information received in the meantime.

Figure 13 displays the scatterplot of the three-month fed funds futures surprises and the S&P 500 stock index. Each dot corresponds to one FOMC statement.

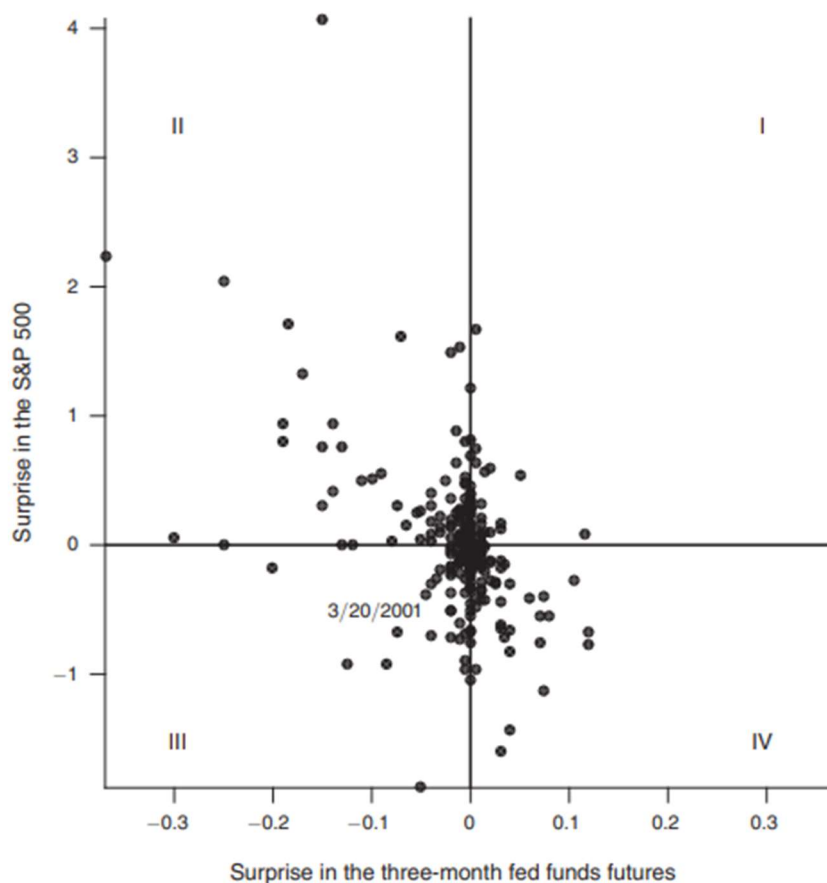


Figure 13: Scatterplot of Interest Rate and Stock Price Surprises (Jarociński and Karadi, 2020).

As shown in the scatterplot, positive stock market surprises complement many positive interest rate surprises, and negative stock market surprises accompany many negative interest rate surprises. At first glance, this may seem rather confusing, since conventional economics suggests that a surprise in interest rates should cause stock prices to move in the opposite direction.

As forecasted by standard economics, quadrants II and IV of the plot portray the negative co-movement between interest rates and stock prices. Indeed, traditional economic models imply that tightening monetary policy leads to a decrease in stock prices. This happens for two reasons. First, monetary tightening creates a contraction that lowers the expected value of future dividends. Second, higher interest rates increase the rate at which these dividends are discounted: consequently, the stock price declines.

In quadrants I and III, however, one can spot the opposite co-movement, which is positive. What's worth noticing is that these latter quadrants contain about a third of the data, a considerable amount.

Interestingly, the case is even stronger for the euro area. Figure 14 shows the scatterplot of the surprises in the three-month EONIA Swaps and EURO STOXX 50 Index.

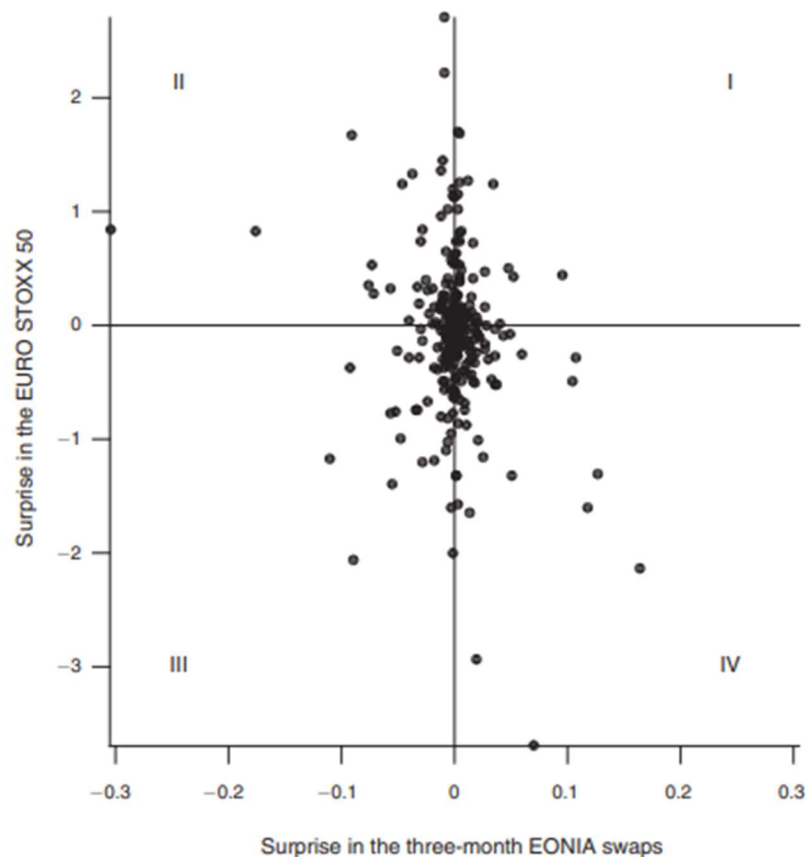


Figure 14: Scatterplot of the Surprises in the Three-Month EONIA Swaps and EURO STOXX 50 Index (Jarociński and Karadi, 2020).

In this case, over 40% of the interior data points fall within quadrants I and III, illustrating wrong-signed stock market responses. This is even more prevalent than in the U.S., which aligns with the ECB's more transparent communication policy.

On this matter, Jarociński and Karadi (2020) build a case demonstrating that these wrong-signed shocks are not triggered by regular monetary policy shocks but are instead caused by information shocks. The authors disentangled these two shocks and used a proxy SVAR to study their economic effects. The main finding is that the immediate stock market response to a monetary policy announcement is informative about the announcement's longer-run economic consequences.

A rise in the interest rate coupled with a stock price drop gives rise to a considerable contraction in output and a tightening of financial conditions, consistent with the impact of a monetary policy shock in standard economic models.

Conversely, an increase in interest rate along with a stock price increase triggers a higher price level and real activity and an improvement in financial conditions. This is what (Jarociński and Karadi, 2020) label as a central bank information shock.

This happens due to a different interpretation of the move made by the central bank. When the central bank foresees strong demand, it typically increases the interest rate to prevent inflation. By raising the nominal interest rate, the central bank is signalling that the “future is bright” to the stock market, leading to a positive reaction.

It is therefore quite clear that the impact of an unexpected increase in the interest rate coupled with a stock price decline is very different from the effects of an unanticipated interest rate increase accompanied by a stock price increase.

Similar conclusions are drawn using an alternate yet complementary methodology in Miranda-Agrippino and Ricco (2021), who also point out that oftentimes the tools used to identify monetary policy shocks may mix the actual policy shock with information about the economic state due to the disclosure of information through the policy action. This *signalling effect* may generate the empirical puzzles often reported in the literature. Indeed, widely used tools for monetary policy shocks constructed in prominent identification schemes assume that either the central bank (Romer and Romer, 2004) or market participants (Gertler and Karadi, 2015) possess complete information. But if this assumption were valid, different instruments would deliver identical results. This is not the case, as many empirical studies still haven't reached a common resolution.

Two important implications for the identifying monetary policy shocks arise from models of imperfect information. First, a common finding is that average expectations respond more gradually to shocks to fundamental shocks than the forecasted variables (Coibion and Gorodnichenko, 2015). This suggests that changes in expectations and fluctuations in market prices can be linked over time and hold information about current and past structural shocks. Secondly, because of the unequal distribution of information between policymakers and

market participants, observable policy actions can communicate information regarding fundamentals (Melosi 2017, Romer and Romer 2000). Indeed, as Miranda-Agrippino and Ricco (2021) observed, agents adjust their expectations by extracting information about the structural shocks from the policy announcement. Romer and Romer (2000) would call this the “*Fed information effect*”, which represents the implicit disclosure of information that can alter the central bank's power to balance the economy.

It is precisely the presence of information frictions that can invalidate commonly used instruments. To overcome this, Miranda-Agrippino and Ricco (2021) proposed a high-frequency instrument for monetary policy shocks that addresses the issue of informational rigidities. This is the proxy that will be used in this paper. Specifically, this instrument incorporates the slow absorption of information in the economy and the signalling channel of monetary policy that emerges from the asymmetry of information sets between the central bank and market participants.

To construct it, the creators initiated the process by predicting unexpected market fluctuations in the fourth federal funds’ futures linked to FOMC announcements regarding Greenbook forecasts. They also considered adjustments made to predictions for real economic growth, inflation (as indicated by the GDP deflator), and the unemployment rate. This was done to account for the central bank's confidential information and associated information transmission mechanism. The regression is the following:

$$FF4_m = \alpha_0 + \sum_{j=-1}^3 \theta_j F_m^{cb} x_{q+j} + \sum_{j=-1}^2 v_j [F_m^{cb} x_{q+j} + F_{m-1}^{cb} x_{q+j}] + MPI_m.$$

Here, $FF4_m$ denotes the high-frequency market-based monetary surprise computed around the FOMC announcement indexed by m , $F_m^{cb} x_{q+j}$ denotes Greenbook forecasts for the vector of variables x at horizon $q + j$ that are assembled prior to each meeting, and $[F_m^{cb} x_{q+j} - F_{m-1}^{cb} x_{q+j}]$ denotes revisions to forecasts between consecutive FOMC meetings. These forecasts can be considered a proxy of the FOMC information set at the time of making the policy decision. The horizon is expressed in quarters, and q denotes the current quarter.

This regression produces a residual instrument for monetary policy shocks (MPI_m) that controls for the transfer of information that implicitly occurs at the time of FOMC statements. The autoregressive component in the monthly surprises is then removed in order to count for

the slow absorption of information by the agents, typical of models of imperfect information. After calculating the cumulative MPI for each month, the result is denoted as $\overline{MPI}_t$. The final instrument is the residual of the following regression:

$$\overline{MPI}_t = \phi_0 + \sum_{j=1}^{12} \phi_j \overline{MPI}_{t-j} + MPI_t$$

Note: The tool MPI_t identifies monetary policy shocks, which represent changes in the policy rate market participants have not anticipated and do not stem from the central bank's concerns about current or anticipated changes in economic conditions.

This instrument will be used in the following regression, as it usefully integrates the slow assimilation of information and the signalling channel of monetary policy that arises from the different information levels between the central bank and market participants.

3.4. SVARs

As proven by Plagborg-Møller and Wolf (2021), valid structural estimation with an instrument (IV) can be carried out by ordering the IV first in a recursive VAR. The second component should be the variable whose exogenous movements need to be identified (in this case, the policy interest rate) and then everything else.

In this case, the regression is testing the following null hypothesis:

$$H_0 : r_t^n \mid D_{\xi_{it}} = 0$$

That is, conditional on an exogenous change in the nominal interest rate (i), the real natural interest rate (r) does not move after a monetary policy shock.

The forecast sample is 1991Q1-2015Q4. The first regression, made via a proxy-SVAR approach à la Plagborg-Møller and Wolf (2021), investigates this hypothesis and places the proxy à la Miranda-Agrippino and Ricco (2021) as the first component. As previously mentioned, this choice results from the Cholesky decomposition and is strengthened by the availability of the exogenous instrument derived by Miranda-Agrippino and Wolf (2021). The regression according to Cholesky's ordering is the following:

$$LS = mpi_ff4 + gs1 + baa10y + 100*\log(cpiaucsl) + 100*\log(rgdp) + rstar_hlw$$

Where mpi_ff4 is the proxy of monetary policy provided by Miranda-Agrippino and Ricco (2021), $gs1$ represents the market yield on U.S. treasury securities at 1-year constant maturity obtained from the Federal Reserve economic data. $Baa10y$ is Moody's seasoned Baa corporate bond yield relative to yield on 10-year treasury constant maturity: it is helpful to include this variable as it informs us of the stock market's performance after a shock in monetary policy. $100*\log(cpiaucsl)$ corresponds to the consumer price index, $100*\log(rgdp)$ is the real gross domestic product and finally $rstar_hlw$ represents the natural rate of interest. These last three variables were obtained from the Federal Reserve economic data. Results are presented in Figure 15, showing the impulse response functions.

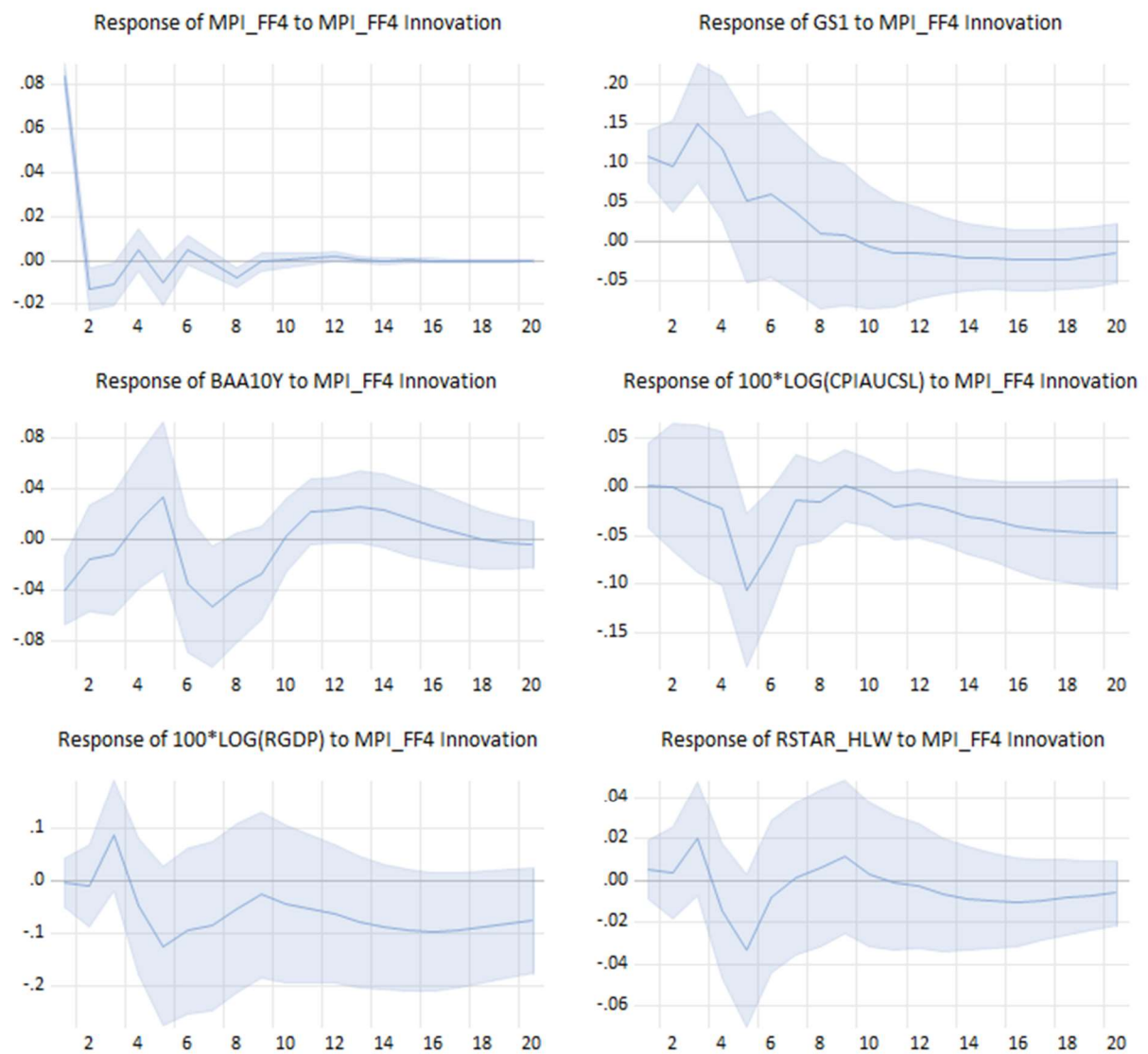


Figure 15: Response to Cholesky One S.D. (d.f. adjusted) Innovations. ± 2 Monte Carlo S.E.s.

The graphs in figure 15 visualise impulse response functions within a Structural Vector Autoregression (SVAR) analysis context. They display how various economic variables react to an unexpected one standard deviation shock in the MPI_FF4 innovations over time. Each graph's horizontal axis signifies the time periods post-shock, while the vertical axis represents the magnitude of the response of the particular economic variable to this shock. The central line traces the mean response of the variable over time, offering insights into its behaviour and potential adjustments following the initial shock. Additionally, the " ± 2 Monte Carlo S.E.s" refers to the shaded regions surrounding each response curve. These shaded areas restrict the bounds of a two-standard error confidence interval, thus highlighting the range in which the true response is expected to lie with a specified confidence level. This shading underscores the degree of statistical uncertainty associated with each response estimate. The graph depicting the "Response of MPI_FF4 to MPI_FF4 Innovation" shows that, as expected, MPI_FF4 shock dies out quickly.

On the other hand, the graph titled "Response of GS1 to MPI_FF4 Innovation" offers insights into the impact of MPI_FF4 shocks on the market yield of U.S. treasury securities at 1-year constant maturity, represented by GS1. Here, GS1 shows a considerable decline in reaction to the MPI_FF4 shock. After the initial drop, GS1's response reduces at a diminishing rate over the periods but maintains a negative trajectory for the observed horizon. This indicates that short-term treasury yields, represented by GS1, have a prolonged sensitivity to disturbances in monetary policy.

With regards to "Response of BAA10Y to MPI_FF4 Innovation", the BAA10Y, which stands for Moody's seasoned Baa corporate bond yield relative to the yield on 10-year treasury constant maturity, reacts dynamically to changes in the MPI_FF4. Bond yield movement gives insights into the stock market's performance in the face of monetary policy shocks. We observe that the BAA10Y initially dips before rebounding and subsequently displays periods of rises and falls. Such behaviour implies that the corporate bond yields, and by extension, the stock market, can be influenced by and adapt to the changes in monetary policy in the short term. On the other side, in the medium-long term we do not observe any relevant influence. Additionally, in "Response of 100*LOG(CPIAUSCL) to MPI_FF4 Innovation", we see the behaviour of the Consumer Price Index (CPI) in response to changes in the MPI_FF4. The CPI's initial reaction is a decline, suggesting a potential reduction in inflationary pressures. However, this is followed by a rise and subsequent fluctuations around the zero mark. This pattern demonstrates the interplay between monetary policy shifts and inflation rates, suggesting that policy changes can affect inflation over different time horizons.

Moreover, in the "Response of $100 \cdot \text{LOG}(\text{RGDP})$ to MPI_FF4 Innovation" graph, we observe the behaviour of the Real Gross Domestic Product (RGDP) following changes in the MPI_FF4. An initial surge is evident in the RGDP after an innovation in monetary policy. This rise in RGDP could suggest a boost in economic productivity immediately after the policy shock. However, as time progresses, the RGDP demonstrates fluctuations above and below the zero mark, indicating the variable and transient nature of the impact monetary policy changes can have on economic growth.

Finally, turning our attention to the "Response of RSTAR_HLW to MPI_FF4 Innovation" graph, the depicted trends represent the reactions of the natural rate of interest, RSTAR_HLW, to changes in the MPI_FF4. The pattern RSTAR_HLW exhibits is characterised by alternating peaks and troughs. This variability underscores the intricate relationship between the natural interest rate and monetary policy. It emphasises that while the RSTAR_HLW may react to immediate policy innovations, its longer-term behaviour remains less affectable. In other words, this regression shows no evidence in favour of the impact of monetary policy on the real interest rate.

In conclusion, the graphs comprehensively analyse the interplay between monetary policy, represented by MPI_FF4, and several crucial economic and financial indicators. Each metric's immediate and varied responses to MPI_FF4 innovations underscore monetary policy's integral role in shaping the broader financial and economic landscape. For instance, the swift reaction of MPI_FF4 to its shocks, coupled with the prolonged impact on short-term treasury yields (GS1), points to the sensitivity of market mechanisms to policy changes. Furthermore, the oscillations observed in corporate bond yields and the broader stock market emphasise the interconnectedness of financial markets and their adaptive nature in the face of policy shifts. Following monetary policy shocks, the observed behaviours of the Consumer Price Index and Real Gross Domestic Product reveal the nuanced relationship between policy decisions and broader economic health and productivity. Lastly, although the natural interest rate (RSTAR_HLW) exhibits an initial fluctuating behaviour in response to policy changes, the results indicate that it is not impacted in the long run. Consequently, these patterns suggest that while monetary policy can influence immediate market and economic conditions, its effects on real variables do not last in the long run.

Nonetheless, it is now appropriate to make an observation. As pointed out by recent research (Fornaro and Wolf 2023, Ma and Zimmermann 2023), monetary policy shocks may exert a long run real effect via their impact on innovation, which eventually works through capital accumulation. Hence, accounting for private productive investment seems to be a-priori crucial to correctly pin down the transmission of such shocks to the real economy.

To understand whether the effect transfers to the production function, it is plausibly helpful to include a variable representing investment, since it is one of the key elements of the production function. For this reason, this section includes another regression, this time incorporating investments:

$$\begin{aligned} LS = & \text{mpi_ff4} + \text{gs1} + \text{baa10y} + 100*\log(\text{cpiaucsl}) + 100*\log(\text{rgdp}) \\ & + 100*\log(\text{INV}) + \text{rstar_hlw} \end{aligned}$$

Figure 16 presents the impulse responses.

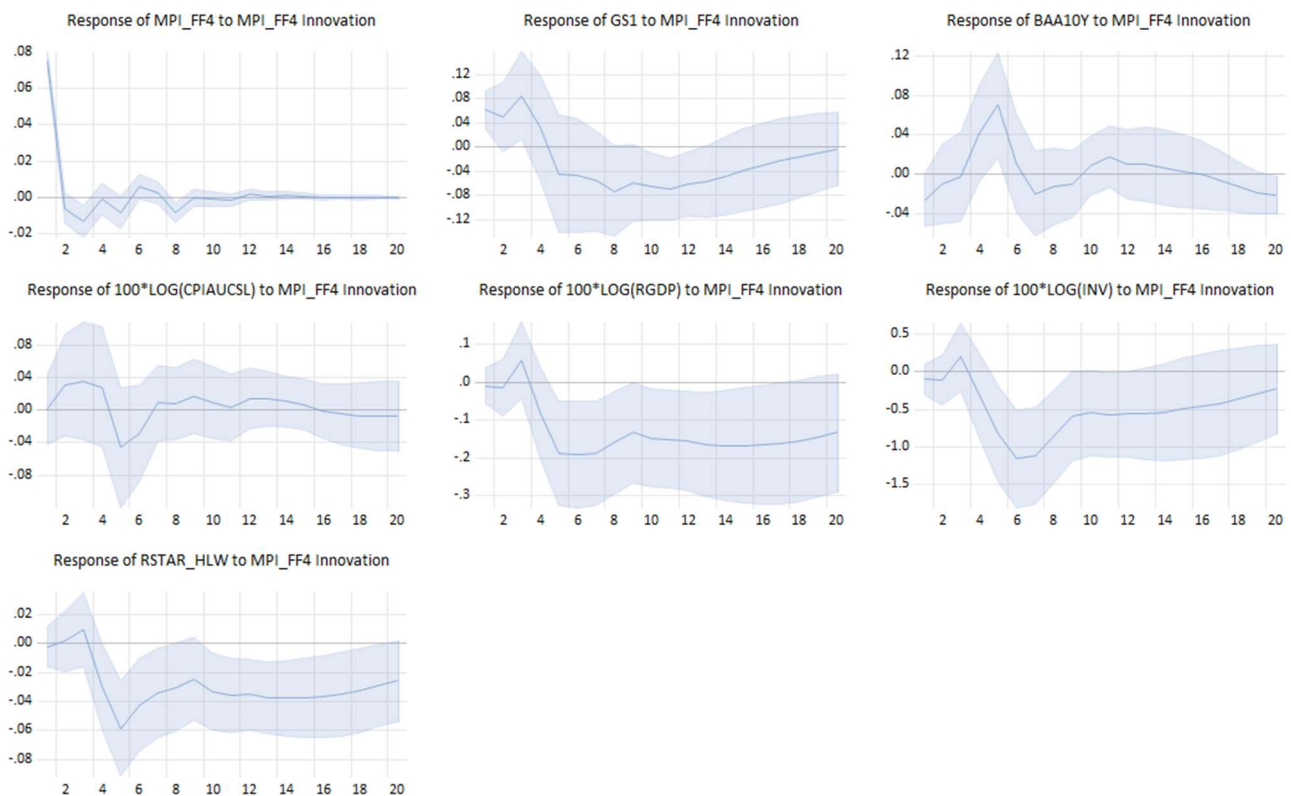


Figure 16: Response to Cholesky One S.D. (d.f. adjusted) Innovations - including 100*log(INV).
± 2 Monte Carlo S.E.s.

The provided graphs present a detailed analysis of the effects of Cholesky One S.D. (d.f. adjusted) Innovations, supplemented with the confidence bands of ± 2 Monte Carlo S.E.s, on various economic indicators. The impulse responses shown in figure 16 provide a different view compared to the first regression.

The first graph, focusing on the response of MPI_FF4 to its shocks, shows similar results to the first regression: the MPI_FF4 shock dies out quickly.

Turning to the second graph, which illustrates the response of GS1 to MPI_FF4 innovation, there is a notable decline. This highlights the impact of monetary policy disturbances on the market yield of U.S. treasury securities at a 1-year constant maturity. The decrease in GS1 is more extended in duration than the self-response of MPI_FF4, emphasising the potential longer-term sensitivity of short-term treasury yields to shifts in monetary policy.

The third graph, showcasing the response of BAA10Y to MPI_FF4 innovation, presents more fluctuations around the average. BAA10Y, which provides insights into the stock market's performance following monetary policy shocks, initially experiences a dip. This initial reaction is then followed by alternating periods of rises and falls. This suggests that seasoned Baa corporate bond yields, which indirectly inform about the stock market's reactions, possess a variable response mechanism to monetary policy innovations especially in the short-term. In the long run, however, BAA10Y is slightly affected by monetary policy innovations.

In the response of $100 \cdot \text{LOG}(\text{CPIAUCSL})$ to MPI_FF4 innovation, we observe a clear pattern of fluctuations over time. This representation corresponds to the consumer price index, which showcases how price levels might adjust following changes in monetary policy. The initial decline is followed by a stabilisation period, emphasising the transient impact of monetary policy disturbances on consumer prices.

Next, the response of $100 \cdot \text{LOG}(\text{RGDP})$ to MPI_FF4 innovation underscores the effect of monetary policy shocks on the real gross domestic product. A notable decline is evident in the early periods, suggesting a possible contraction in the economic output in response to such shocks. As the periods progress, the RGDP demonstrates only a partial recovery.

Moreover, the response of $100 \cdot \text{LOG}(\text{INV})$ to MPI_FF4 innovation reveals the reaction of investment levels to monetary policy innovations. A decline followed by a recovery suggests that investment activities, though initially impacted, seem to partially adjust in the long term. Lastly, the graph delineating the response of RSTAR_HLW to MPI_FF4 innovation provides insights into the behaviour of the natural interest rate in the wake of monetary policy innovations. Notably, RSTAR_HLW's reaction is characterised by a distinct dip both in the short and long term, in sharp contrast to the assumption of monetary neutrality.

The second SVAR, which includes investments, shows evidence supporting the long-term effect of monetary policy on the real interest rate. This suggests that the previous model was misspecified, meaning important variables were omitted from the regression. To put it all together, the result illustrates the role of investment as a crucial indicator to go from the short to the long run and shows that monetary policy shocks are non-neutral, therefore rejecting the null hypothesis formulated at the beginning.

CONCLUSION

After briefly outlining the IS-LM model and the traditional concept of monetary policy neutrality, this dissertation provided a review of some of the key papers challenging monetary policy neutrality.

Fornaro and Wolf (2023) built a case against monetary policy neutrality by researching and outlining the link between monetary policy and firms' automation level. Specifically, the authors introduce the *automation effect*, which presents a new dimension in addition to the classic capital deepening effect. A lower interest rate can lead to a higher number of tasks being performed by capital, as it becomes less expensive. When this occurs, the positive effect of a decrease in the interest rate on productivity is amplified by the automation effect.

However, if the aggregate demand for goods and services remains the same, the increased labour productivity may result in a decrease in firms' labour demand. Indeed, Fornaro and Wolf (2023) highlight that aggregate demand dynamics and productivity's impact on labour demand can potentially counterbalance each other. Monetary tightening can reduce labour productivity because it makes capital more expensive and the use of labour more attractive. For this reason, it may happen that firms demand more labour despite a decrease in demand for their goods. This contrasts with the New Keynesian model, where tightening policy typically leads to diminished employment due to less demand for goods. From this perspective, it is clear that adjustments in monetary policy can lead to unexpected outcomes in the economy. The study's ultimate finding highlights that persistent tightening monetary measures can potentially hinder the adoption of automation technology by businesses and impact the productivity of the overall economy in the long-run.

Ma and Zimmerman (2023) explore the effects of monetary policy on innovation, which happens through alterations in aggregate demand and changes in financial conditions. When demand is reduced through tightening monetary policies, the economic return of developing new products diminishes, thus decreasing the incentives for innovation. Their data shows that patent filings drop following a reduction in monetary policy, with impacts to both public and private companies, and regardless of their size. As for R&D spending, following a 1 percent increase in interest rates over a three-year period, there is a significant decline in R&D spending, with a decrease of about 1-3 percent. In addition, after a monetary tightening, a decline of about 25 percent in venture capital investment and a 9 percent decline in patents take place. The authors also note that tighter monetary policy can affect financial conditions by decreasing the willingness to take risks. This feature of the monetary transmission mechanism, named "risk-taking channel", deals with the impact of monetary policy rates on individuals' perception of risk. Indeed, Ma and Zimmerman (2023) show that VC investments

decline for both early stage and late stage startups after a monetary tightening. The reduction in funding for early stage startups could be in fact due to less interest in investing in risky and not yet established companies. In summary, the study highlights the significant impact of monetary policy on innovation activities. By altering aggregate demand, monetary policy can change the profitability of innovation and the conditions in the financial market. Their findings indicate that monetary policy might influence the long-term productive capacity of the economy, in addition to the widely acknowledged short-term effects.

Jordà, Singh and Taylor (2023) provide another analysis on the matter by conducting a comprehensive cross-country analysis to detect exogenous shifts in monetary policy and assess their repercussions on the long-term output. Their research found that after an exogenous monetary shock, production falls and doesn't recover to its pre-shock trend for even twelve years. More specifically, a 1 percentage point shock in domestic short-term interest rates has a significant and protracted negative impact on GDP. The GDP declined by 4.60 percent during a 12-year period in the entire sample. Capital and Total Factor Productivity (TFP) are the primary determinants of this outcome and both of them fall gradually rather than abruptly following a shock. Conversely, the total number of hours worked tends to revert back to its initial pattern. Put simply, capital stock and total factor productivity (TFP) display long-lasting effects, while labour does not. The findings present evidence of the long-term effects of monetary policy shocks, manifesting signs of hysteresis that extend over a period exceeding ten years.

Finally, this thesis presented an empirical analysis via SVAR à la Plagborg-Møller and Wolf (2021) to measure the potential long-term impact of monetary policy shocks on the natural interest rate and other variables. The Cholesky decomposition was applied to address the issue of correlation between error terms in the SVAR. The instrumental variable used in the analysis was provided by Miranda-Agrippino and Ricco (2021), who constructed an exogenous monetary policy proxy to account for the distorting presence of information shocks (Jarociński and Karadi, 2020). The first regression showed no evidence in contrast with monetary policy.

However, as recent literature points out (Fornaro and Wolf 2023; Ma and Zimmermann 2023), monetary policy shocks can have a lasting impact on the real economy through their influence on innovation, which subsequently affects capital accumulation. Since investment appears to be a crucial indicator for moving from the short run to the long run, a second regression was run, which included a variable for investment. In this case, impulse responses revealed different results. The variable of primary focus, the natural interest rate (RSTAR_HLW), displayed a significant decline in both the short-term and long-term

horizons. This deviates from the conventional wisdom of monetary neutrality, which posits that changes in the money supply shouldn't have protracted effects on the real economy. This observation not only challenges traditional expectations about the stability of the natural interest rate, but also prompts further investigation into the underlying factors contributing to this deviation, their implications for the broader economic landscape, and the potential policy ramifications that may be needed to address this unforeseen trend.

Nevertheless, the author of this dissertation does not necessarily suggest that these results are definitive and indisputable. Surely, further research from multiple angles is warranted to firmly establish the validity of these results. That being said, it is important to embrace a certain degree of skepticism and question traditional assumptions from time to time, as sometimes they no longer seem to accurately represent our reality.

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