EconPol
POLICY REPORT

22
2020
July
Vol. 4

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EUROPE
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European Network for Economic
and Fiscal Policy Research

headed by

EconPol POLICY REPORT
A publication of EconPol Europe
European Network of Economic and Fiscal Policy Research

Publisher and distributor: ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 89 9224-0, Telefax +49 89 9224-1462, email Dolls@ifo.de
Editors: Mathias Dolls, Clemens Fuest

EconPol Europe: www.econpol.eu

The real interest rates across monetary policy regimes

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Abstract

This paper reviews the main theories of interest rate determination and studies the dynamics of the real interest rate in US. Using cointegration techniques we search for equilibrium relationships between the real interest rate, monetary factors and real factors and we study how these relationships change with the policy regimes. We analyze monthly US data since early 20th century and find equilibrium relationships between a measure of the real interest rate, the policy interest rate and industrial production growth only after the end of the Bretton Woods. Moreover, we find that the equilibrium relationships between these variables are not invariant to changes in the monetary policy regime.

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1 Introduction

A central issue in economics is the identification of the main drivers of interest rates. The investigations about the long run determinants of interest rates go back to the beginning of macroeconomics. Early classical references are, for instance, Wicksell (1936) and Fisher (1930), among many other foundational references. More recently and from various different approaches we can cite Feldstein and Eckstein (1970), Feldstein and Summers (1979) or Barro (1987), to name a few. Even though its long standing tradition, this branch of the literature has been recently invigorated. After the Great Financial Crisis that started in 2008 in US, academics and policy makers got concerned about the low levels of nominal and real interest rates and their potential impact in terms of monetary policy space: with interest rates near the Zero Lower Bound (ZLB) Central Banks may lack fire-power to implement counter-cyclical monetary policies in the event of a new crisis.

Over the years, the profession has not arrived to a consensus on the determinants of the long run rates of interest. Moreover, what have been considered the main determinants have evolved one to one with the macroeconomic context. In the 70s, a decade of relatively high inflation worldwide, policy makers and academics considered that the main drivers of long run interest rates were related to monetary factors. As the world economy entered into a period of disinflation and the interest rates started declining in the mid-eighties, the focus on the determinants of interest rates also changed. During this period, researchers and policymakers revised their previous conclusions and ended up associating the importance of monetary policy to accommodating to secular trends, which in turn were considered the ultimate responsible for driving down interest rates. The fall of interest rate accelerated after the 2007 US financial crisis. Interest rates in US dropped quickly, followed by the UK and Europe during its debt crisis. Interest rates were cut as a part of monetary programs that intended to provide liquidity to financial markets. This policy found its limit very fast hitting the ZLB of nominal interest rates with a virtually zero inflation. Initially, this situation was assumed to be short lasting but it is now clear, after 10 years at the ZLB, that low interest rates environment may be very long lasting. Hence, recently, researchers have acknowledged the importance of the demographic structure and technological dynamics in the determination of intertemporal prices.

In this paper we study interest rates dynamics. We start by reviewing the most salient theories on the determination of interest rates, their theoretical background and their empirical support. Then, we study the case of US. We build a small dataset of monetary and real variables at monthly frequency: a high frequency dataset allows us to analyze the drivers of the real interest rate conditional on the different monetary policy regimes, as classified by Benati (2008). In this respect, our contribution is to reconsider the theoretical frameworks for interest rate determination by studying one representative economy using long series of the real interest rates, real and monetary factors at high frequency. The high frequency data allows us to consider sub-sample analysis conditional on different monetary regimes with the objective of analyzing the plausibility of different theories for alternative regimes.

US data suggests there exist an equilibrium relationship between the real interest rate, the monetary policy interest rate and real factors only after the end of the Bretton Woods. The equilibrium (cointegration) vector does not seem to be stable: in particular, it changes when the monetary policy regime changes. Along the equilibrium vector, real factors and monetary factors adjust differently depending on the regime: during the inflation targeting period, there seems to be evidence of a tighter relationship between the real interest rate and the monetary instrument that seems to be absent during the high inflation regime.

We focus our analysis on the drivers of the real interest rate. It is important to highlight that the literature has studied both the real and the nominal rates of interest. For instance, Jordà et al. (2019), Laubach and Williams (2003) and Borio et al. (2017) study real interest rates. Laubach and Williams (2003) objective is to identify the natural interest rate, which is the real interest rate consistent with potential output and stable inflation. Bernanke et al. (2007) also claims that the real interest rate is low and addresses it to the savings glut. Instead, Feldstein and Eckstein (1970) and Gehringer and Mayer (2019) estimate nominal interest rate models. In turn, in their policy speeches, Phillip Lane in his speech at the ECB in November 2019 refers to the low real interest rate while Peter Praet in his speech at the ECB in September 2015 to the low returns of fixed income. One obvious reason why nominal interest rates have been decreasing over the last 40 years is because of the disinflation process. However, nominal interest rates depend on inflationary expectations which are also an endogenous object that depends both on the real and nominal factors and the monetary policy. Global disinflation process, however, does not explain why real interest rates have also been decreasing over the same period.

The remainder of the paper goes as follows. In section 2, we discuss the main modern theories of determination of interest rates: the monetary and financial drivers, technological and demographic drivers, the savings glut, and the secular stagnation hypothesis. In section 3 we undergo a modest, but yet novel, analysis of the determinants of the real interest rates in US with a focus on the role of monetary regimes in shaping the equilibrium conditions between real and monetary drivers of the real interest rate. In Section 4 we review how the main findings regarding the relationship between real and monetary factors change after the Great Financial Crisis. Finally, in Section 5 we briefly discuss our main findings.

2 Determinants of real interest rates

A traditional and still ongoing discussion in macroeconomics is about the drivers of the real interest rates in the long and in the short run. In the literature there are two hypotheses. The first hypothesis highlights the importance of real factors (usually referred as "fundamental drivers") that affect the demand and supply for real savings and investment: the interplay between real saving and investment desires solely determines the real interest rate. The second hypothesis highlights the role of monetary factors, particularly monetary variables and, importantly, monetary policy regimes. Under this second view, the policies implemented by the central bank and the *monetary policy regime* are key for inflation and real interest rates. Here, the supply and demand for credit would play a crucial role: credit, the determination of interest rates, financial regulation and the supply of various assets by the central banks affect the decisions of savers and investors and play a central role in the market interest rates.

Looking at the recent developments in the data both approaches may provide plausible explanations. Under the first approach, the dynamics of the main secular factors highlighted in the literature are consistent with low interest rates: the evolution of demographic trends, the increase in income inequality and world financial integration can be considered as plausible explanations of low interest rates. On the other hand, the same is true for the second hypothesis due to the aggressive expansion of monetary policy, a feature that stressed after the Great Financial Crisis. Another potential problem to identify the importance of real versus monetary factors comes from the fact that the Central Bank itself may be responding, i.e. accommodating its monetary policy, to the secular behavior of real factors. In other words, if the central banks followed feedback rules of the form of, for instance, the Taylor Rule, then monetary factors have not been exogenous to real factors.

The objective of this section is to discuss the main features of both theories and discuss the various forms they have taken in the recent literature. Besides reviewing what the profession has done so far, this section allows us to identify which data is important under each theory and will guide our empirical approach for the rest of the paper.

2.1 Monetary policy and financial frictions

According to the theories that support the importance of monetary drivers, the behavior of interest rates is mainly driven by monetary policy decisions. These policies may be, in turn, miss-aligned to long term fundamentals and potentially determined by business cycle conditions. The Central Bank itself, may not be able to target (or measure accurately) the natural rate of interest and hence interest rates may be permanently away from the full employment zero inflation rate.

Central Banks policies include the management of the short term interest rate, monetary aggregates and macro-prudential policies to achieve price and financial stability. By settling these policies, the bank affects the provision of loans by private banks as well as their lending rates and spreads.

Specifically, Central Bank regulations and liquidity provision policies affect the optimization problem of private banks, which create money through supplying loans and influence the lending rates affecting investment decisions and the business cycle. Notice that, given this interpretation, there is not an immediate channel from savings decisions to interest rate (independently of the Central Bank response to expected savings decisions of the system).

Gehringer and Mayer (2019) associates this view to the work of the Austrian School by Wicksell, Mises and Hayek.

It has been suggested that the main channel for the transition of monetary policy is the impact on credit and investment. As Borio et al. (2017) highlights, the impact of monetary policy on credit and investment, i.e. the financial cycle, may be an important channel but not the only one. The monetary policy may continuously affect the economy due to non-observability of the natural interest rate and a consequent continuous impact of miss-alignment of the monetary policy interest rate and the natural interest rate, as well as the impact on expectations and portfolio rebalancing of investors.

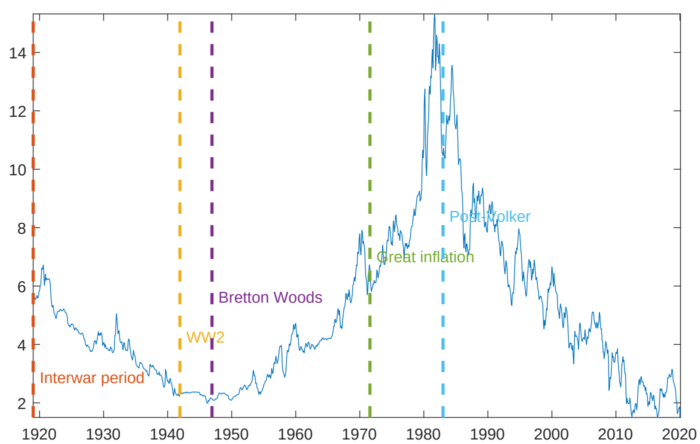


Figure 1: Nominal Interest rates and monetary policy regimes

Note: Net nominal interest rate for US in percentage, constructed by the authors according to the methodology described in Section 3. Monetary regimes are defined as in Benati (2008).

The literature studying the role of monetary factors on interest rates has focused on the role of monetary policy instruments. However, Borio et al. (2017) interestingly highlights the role of the monetary regime itself. In their paper, the authors find strong impact of monetary regimes on interest rates behavior. They show that changes in the monetary regime from the gold standard, the Bretton Woods and the Inflation Targeting regimes seem to correlated with large swings in the behavior of interest rates. Figure 1 plots the US long run net interest rate in percentage together with the dates in which new monetary policy regimes started, as documented by Benati (2008). As seen in the picture, since 1920 Benati (2008) identifies five different regimes, we could extend it to six if we separate the post-Volker regime in the pre-2008 crisis and post 2008 crisis. The picture provides some suggestive evidence that monetary regime may exert substantive impact on the rates of interest. In sample, there are two large periods where the interest rate trends down (the interwar period and the post-Volker period) and a large period with interest rate increases. The interest rate volatility and persistence also seem to be different across regimes.

2.2 The role of economic fundamentals

The working hypothesis of a large part of the literature is that the real interest rates (in the long run) are driven by savings and investment desires, which depend essentially from the real side of the economy and theoretically can be associated to the Neoclassical Growth Model. The interaction between savings supply and investment demand sets a natural interest rate around which short term interest rates fluctuations gravitate. According to this theory, the real interest rate is the equilibrium price that results from the interaction of investment and savings decision. The main drivers must be related to any factor that drives savings and investment, domestically or internationally. In particular, the literature has pointed as main determinants of savings and, hence, the interest rates to those associated to population growth and aging, and domestic and external savings behavior both from the side of supply and demand. Investment decisions, in turn, drive the demand for savings and also affects equilibrium rates. High expected output growth, technology and productivity growth, and the marginal product of capital have first order impact on investment rates. Other factor is the emergence of key international actors, as China and India, or more in general the emerging world that launches new investment opportunities with high expected yields together with a growing context of international financial integration and development. These considerations are behind a strong potential driver of interest rates known as the global savings' glut hypothesis as in Bernanke et al. (2005), that we discuss below.

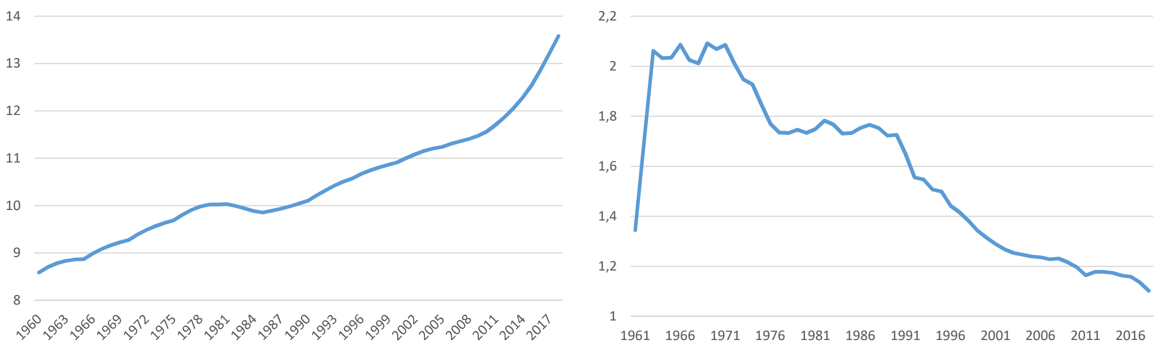
Behind the hypothesis that investment and savings desires determine long run real interest rates (or its gravitational level, the natural interest rate) there is the implicit assumption of perfectly operating financial markets that do not fail to transmit through prices the relative scarcity of funds. This is a strong assumption, specially thinking in terms of long run data, due to the fact that there have recently been increasing trends of financial integration.

Several of these hypotheses are clearly discussed in Borio et al. (2017), Bean et al. (2015) and Gourinchas and Rey (2016). Here we briefly discuss the main aspects of those hypothesis.

2.2.1 The role of demographic factors

Figure 2 presents the long run dynamics of some key demographic statistics at a world-wide level. As can be seen in the figure, over the last 50 years population growth slowed down and old age dependency ratio increase more than 50%, an outcome that results both from an increase in life expectancy together with the slowdown in population growth.[1] The trends of demographic factors have been considered drivers behind the decline in interest rates. The impact of recent trends of these variables are not, however, affecting interest rates and aggregate savings into a clear direction. In particular, the increase in the age dependency ratio pushes interest rates down due to the fact that households that are currently at working age have a larger desire to save. Additionally, these demographic dynamics also increase the share of older (retired) households relative to working age households implying that an increasing part of the population is mainly dis-saving, which should be expected to push interest rates up.

[1] Measured as the ratio of older dependents (older than 64) to working age population (15-64 years old): the percentage of older than 64 per 100 working-age population.



(a) Age dependency ratio (b) Population growth

Figure 2: World demographic statistics

Note: This figure presents the World Age dependency ratio (old) and the World growth rate of population. Data is from the World Development Indicators database from the World Bank.

As highlighted in Bean et al. (2015), demographics also affected the demand for investment due to the implied fall in the labor force participation.

2.2.2 Technology growth, innovation and the relative price of capital goods

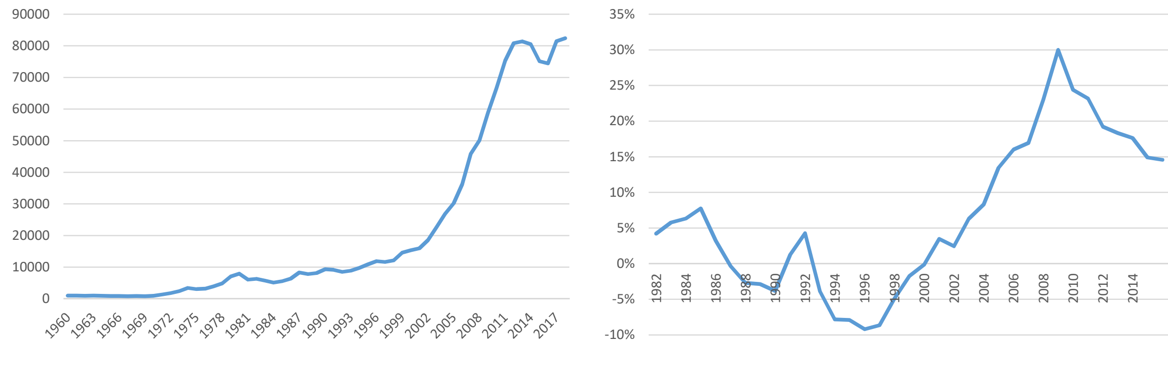
The recent trends in technology growth slowdown and the decline in the relative price of capital may be pushing for a lower demand of investment goods. Moreover, even for a given demand of investment goods, the decline in its price implies that less savings is required. Overall, these factors, imply low investment desires that in turn pushes down the natural interest rate. Bean et al. (2015) elaborates deeply on these factors.

The evolution of these factors impact also on the potential and expected growth. A decrease in expected growth is likely to put pressure down on investment demand and on the real interest rates.

2.2.3 The savings glut

Besides the role of technology and population growth described in the previous section and usually described as main drives of the real interest rate due to the implications of the Neoclassical Growth Model, there have been recently an emergence of new fundamental factors that seem to be empirically relevant. The idea that foreign demand for US safe assets drives down the interest rates goes back to the mid-nineties, when Alan Greenspan, former FED Chairman, referred to it as a "conundrum" of low interest rates. These factors, as the technological and demographic ones, operate through demand and supply of saving. Figure 3 presents evidence regarding two important sources of safe assets demand that are behind the savings glut hypothesis. This hypothesis is closely related to the development of international financial markets and the development of low and mid-income emerging economies, including the small open economies and the large economies such as China and India.

Bernanke (2015) argues that the development of China, other Asian economies and saving desires of Oil exporters are behind the demand for safe assets and represents a major factor driving the long term interest rates down. Since the mid-nineties many of the economies in the emerging markets world became savers in international asset markets. For a given investment level, these economies introduce an excess demand for savings at moderate interest rates pushing them down. In line with this hypothesis, China trade and exchange rate policies, as suggested by the figure, pushes up the demand for safe assets, as reflected in the net foreign asset position. Figure 3 presents relatively recent evidence but Eichengreen (2015) reports that the secular trend in global savings rate increased from 15% at the beginning of the 20th century to almost 30% before the Global Financial crisis.



(a) International reserves in LA

(b) Net foreign Asset Position: China

Figure 3: International demand of safe assets

Note: This figure presents the average international reserves measured in current US dollars (in million). Data include: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru, Uruguay and Venezuela. Net Foreign Asset Position for China is from Milesi-Ferretti and Lane (2017) as % of GDP in domestic currency.

Accumulation of international reserves, safe assets issued in developed economies denominated in US dollars or Euros, explains also a large part of the demand of assets from emerging countries. The main objective for this demand is to gain policy space for exchange rate management and self-insurance for the possibility of international shocks.

Even though this hypothesis is appealing, it has not necessarily been widely accepted. Warnock and Warnock (2009) studies the savings glut hypothesis empirically. They use monthly data from January 1984 to May 2005 and find that international demand of US bonds has a significant impact on the 10 years Treasury yield. However, they find that international capital flows in that period are not the main driver of long term interest rates as inflation expectations and interest rate volatility seem to be more important.

2.3 Secular Stagnation and the role of policies

The low interest rate is, then, one manifestation of what is called "the secular stagnation hypothesis". The term "secular stagnation" was coined by Hansen (1939) to describe the period that started with the Great Depression and lasted until the beginning of the 1940s in US and was characterized by a population growth slowdown, low growth and interest rates. In the current context, Summers (2015) suggests that the combination of low interest rates, low inflation and low economic growth (and expected growth), intensified after the financial crisis, indicates that a persistent period of stagnation may be back. According with Eichengreen (2015) there are four features under the secular stagnation hypothesis: a rise in global savings (i.e. the aforementioned savings glut or scarcity of safe assets may be one of the drivers of the secular stagnation), demographic trends due to low growth rates of population, negative technology dynamics and a fall in the relative price of investment (which implies that to undergo an investment project, if investing becomes cheaper, it may be needed lower amounts of savings).

Besides the long-run drivers depicted above, another source of variability of the real interest rate are more related to the business cycle, demand conditions, output and potential output. The short run behavior can be, to some extent, explained by demand conditions and expected output growth. Currently, these factors are still related to the consequences of the Financial Depression, including the debt overhang that was suffered at all levels of the economy and is currently still dragging down economic recovery.

What is the role of monetary policy for the advocates of this theory? If monetary policy intends to contribute to macro stabilization its role is to accommodate to the secular trends and has to take structural considerations as given. In turn should also respond to the weak economic conditions. In this context, however, there seems to be an inability of the central banks to appropriately affect interest rates and financial markets which may be limited by the policy space in case of a macro crisis. Given the limited space for monetary policy, Eggertsson et al. (2016) and Summers and Rachel (2019) advocate that in these situations there is space for fiscal policy interventions to deal with the secular stagnation and to avoid international spillovers. Interestingly, this line of work highlights the impact of policies, other than monetary policy, in the determination of interest rates in the short run.

3 Empirical assessment

The previous section discussed the main theories of interest rate determination. In this section we look at the data to shed light on the way the dynamics of interest rates have related to those of monetary and real factors in US over the last hundred years. Our objective is twofold: (1) we want to study the existence of equilibrium relationships between the interest rate, potential real and potential nominal drivers; and (2) we want to analyze the short run response of these drivers around those equilibrium relationships.

The empirical literature has mainly focused on studying the impact of the fundamental drivers and on identifying the natural interest rate. Examples of this line of work are, for instance, Borio et al. (2017) and Laubach and Williams (2003). Both papers consider the natural interest rate and then study which factors explain it. Gehringer and Mayer (2019), focusing on the nominal interest rate, pushes for the importance of monetary drivers, as Borio et al. (2017) for the real rate, over the fundamental factors. In contrast, we are interested in modeling the equilibrium relationships, not long run equilibrium or the natural rate. That is, our main interest is not to discuss the importance of fundamental factors on the secular and short run behavior of the real rate vis-a-vis the role of monetary factors. Instead, we are interested in the role of monetary and real drivers in the determination of the interest rates and its dynamics regardless of the horizon of interest. There are two reasons for this choice. First, currently both theories seem to be supported by the data given the low expectations of output growth, the low levels of policy rates and high degree of liquidity of the system and the secular real dynamics make both hypothesis plausible; second, on the other hand, monetary factors respond to secular factors (additionally, due to the non-observability of the natural interest rate monetary policy may be continuously driving the real interest rate away from the natural interest rate).

Econometrically, the concept of equilibrium relationship is related to the concept of cointegration. Even though several authors associate the idea of cointegration to the long run relationship between variables, in this paper I will favor the idea of equilibrium relationship more than that of long-run relationship. The reason is that I consider this relationship may not be invariant to the policy changes, which had happened recurrently in the US over the last century, see Benati (2008). Variables can be cointegrated only if they are non-stationary and of the same order of integration. Consequently, we start studying the properties of the data and then inquire about the relationship among them.

3.1 The data

We collect the following data from FRED St. Louis Fed: consumer price index, Nominal Federal Funds rate, Discount rate of the New York Fed, Yield on Long-Term United States Bonds, Industrial production index, Population and population older than 55 years. We use data on total factor productivity from Bergeaud et al. (2016).

With the CPI (from January 1913 to January 2020), we construct a measure of inflation rate (log difference with respect to the same month the previous year to remove seasonality). We also construct a measure of expected inflation by computing the average monthly inflation rates (with respect to previous month) from the previous year in annual terms, i.e. expected inflation is proxy by the average of the last 12 months' inflation rates.

We construct a long series of the monetary policy nominal interest rate by using the Discount rate of the New York Fed as a proxy for the policy interest rate when the Federal Funds rate is not available. Data for the Federal funds rate starts in July 1954 and runs until January 2020. The NY Fed discount rate is available from November 1914 to June 1969. For the overlapping period both rates have approximately the same level, although the Federal funds rate is more volatile.

We construct our series of the long run interest rate by extending backwards the Long term interest rate for US from Monthly Monetary and Financial statistics from OECD (from april 1953 to February 2020) using the yield on long-term United States Bonds from FRED (that is available since January 1919). In this case we use the growth rates of yield from FRED's data to construct backwards the series starting from the first observation in the OECD database. The real interest rate is the computed by removing the annualized expected inflation accordingly to the Fisher equation.

For all the data, except population data, we have monthly series since 1920 or before. Productivity series are originally at annual frequency which we interpolate using one dimensional spline interpolation. Population data (CNP16OV series from FRED) is at monthly frequency but starting in 1948 (population growth is computed as log difference with respect to same month the year before). Using population data, we compute a proxy for age dependency ratio: in particular we use population of 55 years and older to our measure of population (CNP16OV) to measure the population aging. We use the 12-month industrial production index growth (log difference with respect to same month of the previous year) as a proxy to output growth. Following Borio et al. (2017), on top of this data we include the information in Benati (2008) about monetary policy regimes, that for convenience we present in Table 1, in US who dates monetary policy regimes in US since the eighteenth hundred.

Table 1: Monetary policy regimes in US

Period	Starting month	Ending month
Interwar period	January, 1919	December, 1941
2nd World War	January, 1942	December, 1946
Bretton Woods	January, 1947	August, 1971
Great inflation	September, 1971	January, 1983
Volker stabilization	February, 1983	end of sample

Note: The classification follows Benati (2008), who provides detailed events and days for the starting and ending of each regime, we round them up to the corresponding month.

Our object of interest is the long run real interest rate, which is shown in Figure 4 in percentage terms together with the different monetary policy regimes as documented by Benati (2008). Three features of the interest rate data are easily seen in the figure. First, the real interest rate has been steadily declining since mid-1980s, with a more volatile behavior in the years after the financial crisis until 2012. Second, the recent level of the real interest rate is low when compared to the last 40 years but does not seem low when we consider the whole sample, it is however, less volatile. Third, as already discussed by Borio et al. (2017), the real interest rate suffers strong changes coinciding with changes in monetary regimes. As suggested by Bean et al. (2015) the current low levels of interest rate may be different from the ones during the 50s to 80s as the economy was a postwar economy with periods of financial repression. This way is one way in which monetary policy may play a key role in determining the path of real interest rates. In what follows we study the behavior of the real interest rate, and its co-movement with relevant variables over different regimes.

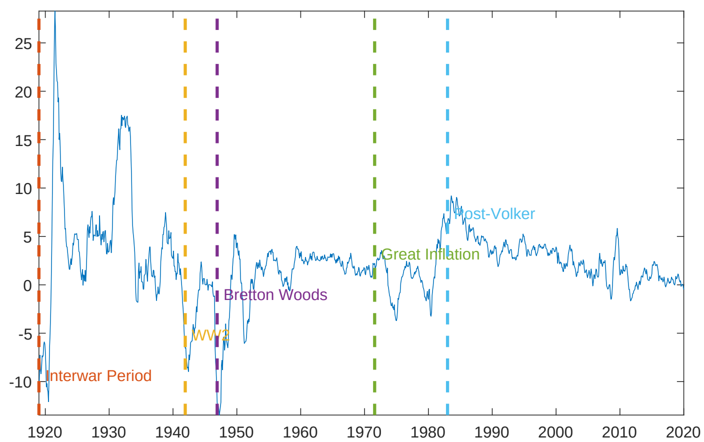


Figure 4: Real Interest rates and monetary policy regimes

Note: Net real interest rate for US in percentage, computed from the ratio between the gross long-term interest rate in annual terms to the annualized expected gross inflation measured as the average inflation of the previous twelve months. Monetary regimes are defined as in Benati (2008).

We supplement the previous figure with Table 2, that presents a few descriptive statistics for the real interest rate. Besides the mean and volatility for the whole sample and subsamples, we also present the correlation between the real interest rate and the twelve months' inflation rate, the policy nominal interest rate and the twelve months growth rate of the industrial production index. As seen in the table, the statistics that characterize the behavior of the real interest rate change substantially conditional on the monetary policy regime.

First, as discussed before, the low level of the real interest rate over the last 40 years is not so unusual. In fact, particularly during the second World War and the Bretton Woods, the real interest rate has also been of a similar order of magnitude. What is a new feature is the low volatility of this variable.

The comovement with inflation, the nominal policy interest rate and measures of real activity such as the growth rate of the Industrial Production Index has also changed over the last hundred years. For instance, the only period in the sample in which the real interest rate is positively correlated with inflation is during Volker disinflation period, the period in which the Federal Reserve Bank were more aggressive with respect to inflation. Also this period, is the one where the real interest rate had the strongest comovement with the policy interest rate.

Table 2: Real interest rate, descriptive statistics (in %)

	Full	Pre-ww2	Bretton Woods	Great Inflation	Post-Volker
Mean	2.3	4.6	0.95	1.2	2.8
Volatility	4.5	7.1	3.3	2.5	2.2
	(0.12)	(0.4)	(0.19)	(0.21)	(0.1)
Corr. w/inflation	-82	-96	-89	-62	18
	(2.4)	(5.8)	(5.2)	(5.3)	(0.83)
Corr. w/policy r	16	4.5	29	7.8	76
	(0.53)	(0.91)	(1.6)	(1.1)	(3.4)
Corr. w/ip g	-27	-42	-17	18	21
	(0.78)	(2.5)	(1)	(1.6)	(1)

Note: data treatment is explained in Section 3. Standard errors in parenthesis.

From the evidence presented in this section, it seems it may be key to study the determinants of the real interest rate conditional on the monetary policy regime. For this approach, we need long term data to go back to include as many policy regimes as possible and high frequency given that some policy regimes may not have been in place for too long. Our approach differs, for instance, from the one in Gehringer and Mayer (2019) and Borio et al. (2017). The approach in Gehringer and Mayer (2019) studies quarterly data for the nominal interest rate from 1990s to 2017. As seen in the previous figure, the period corresponds to one type of monetary policy and international context. Within this period interest rates, both real and nominal, are downward trending and only recently are approaching very low levels. Over the very long run, as seen in the figure and also described in Jordà et al. (2019) the interest rates are following large swings but low rates are not so rare, low nominal and real interest rates have been observed in the past, both in war times, and normal times. For this reason, our approach in this paper is to consider a long sample of interest rates.

A second reason to consider large sample with relatively high frequency is to be able to estimate equilibrium relationships for our data conditional on monetary policy regimes. Most existing studies, with the notable exception of Borio et al. (2017), have focused in recent data and, consequently, in the latest inflation targeting period. However, Borio et al. (2017) in contrast to us, work with annual data.

3.2 A model for the real interest rate

Based on the previous section's evidence, we study the equilibrium relationship between the real interest rate, monetary and real variables for different monetary policy regimes. We exploit the concept of cointegration. To analyze cointegration between macro variables we need that all variables are non-stationary and with the same order of integration. Intuitively, non-stationary variables may wonder arbitrarily far apart as long as they are not cointegrated, if cointegrated non-stationary variables fluctuate along an equilibrium relationship among them. However, if variables are cointegrated, its equilibrium relationship may not be stable across sub-samples, implying that it may change or disappear. It is important to highlight, though, that establishing a cointegration relationship does not imply causality, i.e. we will not be able to conclude whether monetary factors or real factors determine the path of the interest rates.

The next section studies whether the data is stationary across regimes and then we design a small three variable Vector Error Correction (VEC) model for the relevant sub-samples.

3.2.1 Non-stationarity in macro data: unit root analysis

Table 3 present the results from the augmented Dickey-Fuller test for unit roots for each sub-sample conditional on optimal lag structure.[2]

Table 3: Unit root tests for interest rates and candidate factors

	Full	Pre-ww2	Bretton Woods	Great Inflation	Post-Volker
Real Rate	-6.1	-4.1	-4.4	-1.2*	-3.1*
Long term Yield	-1.3*	-1.3*	-2.9*	-1.7*	-3.4*
Policy Rate	-2.9*	-3.3*	-4.1	-2.3*	-2.3*
Age Dep Ratio	2.2*	-	-1.1*	-2.4*	-0.95*
Population growth	-2.6*	-	-3.6**	-2.6*	-2.9*
IP	-2.4*	-1.2*	-2.4*	-1.9*	-2.3*
IP growth	-6.1	-3.4*	-4.4	-2.8*	-3.56**
TFP growth	-6.9	-2.7*	-3.99	-3.48**	-3.55**

Note: We estimate the models with constant and trends and include the optimal number of lags suggested by BIC. (∗) indicates significance at 5% and (∗∗) at 1%.

As usually in practice, results do not imply a clear cut in many cases, even though for most of the variables and samples the number of lags and specification of the model do not affect the conclusions of the test. Particularly, results are robust for the real rate in all regimes. For Policy rate in Bretton Woods including all lags suggested by AIC (26) we find different results and a strong evidence for unit root. Moreover, the policy rate during the

[2] When computing the optimal lag structure, we allow for 24 lags as we use monthly data. As usually, different statistics may conclude different optimal lag structure. In all the cases, we pick the shortest lag structure implied by these tests. For the **Real interest rate** the full sample, Pre-ww2, and Bretton Woods we include 14 lags; for the Great inflation period we include 1 lag (we check also with 13 lags as suggested by other criteria but the unit root remains); for the post-Volker period we include 12 lags. For the **Policy rate**, for the full sample, the trend is not significant and removing the trend we reject the unit root at 5% but not at 1% (with 13 lags). The lag structures are: for the full sample (13 lags), Pre-ww2 (1 lag), and Bretton Woods (3 lags), the Great inflation period (2 lags) and for the post-Volker period (1 lag). For the **Long term yield** for the full sample (2 lags), Pre-ww2 (2 lags), and Bretton Woods (3 lags), the Great inflation period (2 lags) and for the post-Volker period (2 lags). For the **Age dependency ratio** for the full sample (5 lags), and Bretton Woods (0 lags), the Great inflation period (0 lags) and for the post-Volker period (1 lag). For the **Population growth** for the full sample (12 lags), and Bretton Woods (13 lags), the Great inflation period (0 lags) and for the post-Volker period (12 lags). For the **IP growth** for the full sample (13 lags), Pre-ww2 (1 lag), Bretton Woods (13 lags), the Great inflation period (1 lags) and for the post-Volker period (12 lags). For the **IP** for the full sample (3 lags), Pre-ww2 (13 lag), Bretton Woods (2 lags), the Great inflation period (1 lag) and for the post-Volker period (5 lags). For the **TFP growth** for the full sample and all subsamples except Pre-ww2 (17 lags), Pre-ww2 (4 lags).

Great Inflation is stationary in first differences with 1 lag (BIC) but not with 12 lags (AIC), however we analyze also the results with Phillips-Perron unit root test that unambiguously reject the unit root hypothesis in first differences. The TFP growth for the post-Volker period share is barely not unit root at 5% but including 29 lags as suggested by AIC the test cannot reject the hypothesis of unit root. Finally, there is, however, evidence that the IP may be I(2) in the Pre-ww2 and the Bretton Woods (under the AIC but not under BIC), for this reason we also consider the 12-month growth rate of IP index as a potential factor: in this case we find some weak evidence of unit root, barely not significant at 5% but significant at 1% in the post-Volker sample, even though significance disappears when more lags are included.

As seen in the table, we can observe major differences in the interest rates. The real interest rate is a stationary variable for all the sample before the Great inflation period (we do not consider the period during the Second World War). Instead, the long run yield and the policy interest rate are non-stationary for most of the sample. As for potential factors on the real side of the economy, we work with the age dependency ratio, computed as the ratio of population older than 55 to civilian population older than 16, inter-annual population, IP and TFP growth (in log-differences with respect to same month of the previous year) that are also non-stationary for most of the sample.

Running the same test on first differences we find no evidence of unit root, with the exception of the cases specified before, which suggests in most of the cases our data is $I(1)$. Based on this table, we can study cointegration between monetary and real factors and the real interest rate for the periods after the Bretton Woods. We focus on analysis for the next section in these subsamples.

3.2.2 Equilibrium: the real interest rate, Fed funds rate and IP growth

We study the equilibrium relationship between real interest rate, monetary factors and real factors, for the real factor we choose the inter-annual growth rate of the Industrial production index. We estimate the following model

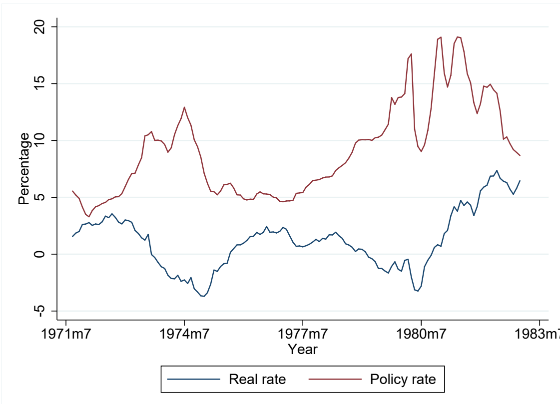
$$\Delta y_t = \alpha\left(\beta y_{t-1} + \mu + \rho t\right) + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \gamma + \epsilon_t$$

Here, y_t denotes the vector of endogenous variables in the model, we allow for a constant in the regression and in the equilibrium condition, γ and μ, respectively, and we allow for a trend in the equilibrium conditions but not in differences. We consider 2 and 3 equation models including different combinations of all variables with the real interest rate. We focus the rest of the analysis in the IP growth, the monetary policy rate and the real rate because studying 2 and 3 equations models with the remainder of the variables seems to reject the cointegration hypothesis.

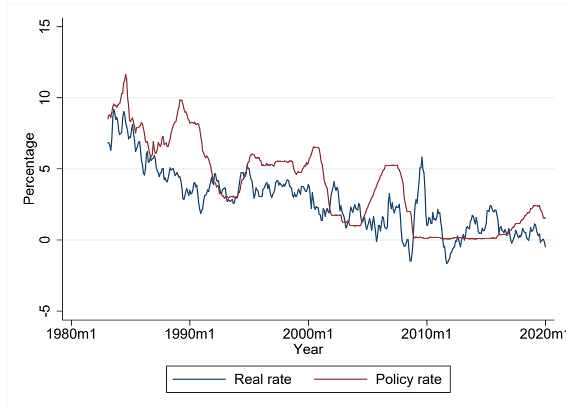
Before going into the analysis of equilibrium relationships, it is worth noticing that the results so far do not seem to support the hypothesis of a cointegration, by subsamples, between usually described fundamental drivers such as population and TFP growth as well as age dependency ratio with the real interest rate. This, itself, is an interesting finding. This does not imply that changes in these variables are unrelated to the real interest rate, but it seems to indicate the behavior of these variables are not part of a long-run joint behavior conditional of policy regimes. In particular, in the remainder of this section we show that monetary drivers and the industrial production index growth are cointegrated with the real interest rate in the inflationary period and during the Volker disinflation. Interestingly, the literature has associated the output growth (proxy here by IP growth) as relevant for the two main hypothesis of interest rate determination.

Two equations models

Figure 5 shows the IP growth and the monetary policy interest rate together with the real interest rate for each sub-sample. As seen in the figure, the co-movement of the data is remarkably different across samples. First, the interest rates seem to be slightly trending up before 1983 and have a negative trend during the Volker disinflation. About their comovement, we can see that during the Great Inflation period, increases in the real interest rate are negatively correlated with the policy interest rate, with the policy rate leading. This behavior is less clear after 1983. The joint behavior of the real interest rate and the IP growth seems to have also changed, particularly before the early 80s there is a strong co-movement with similar amplitude of cycles while after Volker it seems the two variables have detached to some extent with smaller cycles for the real interest rate and changes in the co-movement during some periods.

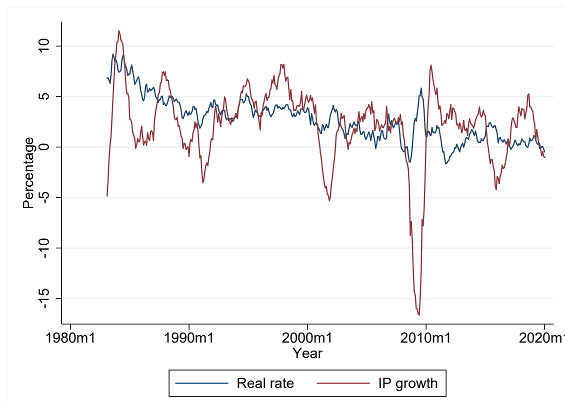


(a) Great inflation period



(b) Post-Volker disinflation

(c) Great inflation period



(d) Post-Volker disinflation

Figure 5: Real and policy interest rates by sub-samples

Note: data treatment and sources are discussed in Section 3.

Before moving to the three-equation model, we can briefly discuss the findings of a bi-variate analysis as a first approach to the data. We find that it seems unlikely that monetary policy interest rate and the real interest rate alone share a common trend before 1983. This same finding seems to hold also with IP growth. particularly, in both cases when selecting the number of lags for the specification of the model, different criteria seem to favor different lags length. When few lags are included, the test finds no cointegration. Instead, with 12 and 14 lags respectively, the existence of cointegration depends on the assumptions about the model. For the period 1983 to 2020 the data tends to suggest the existence of one cointegrating relationship.

The failure to detect cointegration may be a consequence of missing variables. This implies that there may still be an equilibrium relationship between real interest rate and real and nominal factors once we introduce other relevant variables, for this reason, we consider the three-equation VEC model that includes the real interest rate, monetary policy instrument and the IP growth.

The three-equations model

In this section we assume our model is given by the vector $y_t = \{\gamma_{ip,t}, R_t, I_t\}$, that is, it includes the real interest rate (R), the monetary policy interest rate (I) and the 12 month growth rate of the industrial production index(γ_{ip}). As in the two variables case we estimate the models for the 1971-1983 sub-sample and for the 1983-2020 sample due to the change in policy in 1983.

Table 4: Johansen cointegration test for $y_t = \{\gamma_{ip,t}, R_t, I_t\}$

Sub-sample: 1971m9-1983m1			Sub-sample: 1983m2-2020m1		
Rank	Trace Stat.	5% crit val	Rank	Trace Stat.	5% crit val
0	71.98	42.4	0	47.0	42.4
1	28.41	25.3	1	25.7	25.3
2	3.58*	12.2	2	8.1*	12.3
Number of obs: 137			Number of obs: 444		

Note: In both cases we allow for a constant and a restricted trend. We include 13 lags.

Figure 5 suggests the possibility of a very mild trend before 1983 and a negative trend after 1983. We estimate the models with a level trend and not for the model in differences. The optimal number of lags are selected to 2 or 13, depending on the criteria. When running the model with 13 lags we find some significant high order coefficients. For this reason, we decide to consider the model with 13 lags. According to this specification, the Johansen test (with results in Table 4) detects 2 cointegration relationships for each sub-sample. Table 5 presents the normalized cointegration vectors, using the Johansen normalization. As seen, the trend seems to be statistically zero but removing the trend does not change the number of cointegration equations.

The data, then, supports the existence of equilibrium relationships between real and monetary factors. Interestingly, the equilibrium relationship between the variables seem to change across sub-samples. In the Table 5 we also show that the short run adjustment from deviations of the equilibrium relationship also depend on policy regimes. Moreover, except for the nominal interest rate pre-Volker, all variables tend to adjust to restore equilibrium. All variables, however, seem to adjust faster before 1983 than in the Inflation targeting period.

Even though the Johansen test suggest two cointegrating relationships, when estimating the VEC model, we find that a joint test over coefficients for the first cointegrating equation cannot reject that jointly all coefficients are zero, for the two sub-samples. In the table it can be observed that also each coefficient in the first cointegrating relationship are statistically zero. Hence, we reconsider the model assuming only one cointegrating relationships.

3.2.3 One cointegration vector model

Even though the Johansen test favors the existence of 2 cointegrating relationships for each sub-sample, the VECM estimation suggests that one of the relationships in each sub-sample is not significant and all its estimated parameters in each relationship are not significantly different from zero. We then re-estimate the VECM with only one cointegrating relationship for each sub-sample.

The first block in table 6 presents the estimates of the cointegration relationship for the two subsamples. As seen in the table there is a change in the equilibrium equation across samples. The relationships are remarkably different. During the great inflation period an increase in the growth rate of the economy required an increase in the real rate and a drop in the monetary policy rate to restore equilibrium while in the Volker disinflation period it is

Table 5: Johansen cointegration vectors for $y_t = \{\gamma_{ip,t}, R_t, I_t\}$

Sub-sample: 1971m9-1983m1				
Cointegration vectors				
Coefficient	Value	Standard error	Value	Standard error
	Vector 1		Vector 2	
γ_{ip}	1	-	0	-
R	0	-	1	-
I	0.0018	0.0022	-0.88	0.286
Trend	0.00008	0.0002	0.003	0.023
Constant	-0.041	-	5.299	-
Adjustment coefficients				
Coefficient	Value	Standard error	Value	Standard error
	Cointegrating equation 1		Cointegrating equation 2	
γ_{ip}	-0.158	0.054	0.0016	0.0005
R	0.45	2.29	-0.05	0.021
I	14.83	3.8	-0.045	0.035
Trend: restricted trend				
Number of obs: 137				
Sub-sample: 1983m2-2020m1				
Cointegration vectors				
Coefficient	Value	Standard error	Value	Standard error
γ_{ip}	1	-	0	0
R	0	-	1	-
I	-0.0034	0.003	-.66	0.185
Trend	0.00002	0.00008	-.00047	0.0045
Constant	-0.0377	-	1.27	-
Adjustment coefficients				
Coefficient	Value	Standard error	Value	Standard error
	Cointegrating equation 1		Cointegrating equation 2	
γ_{ip}	-0.043	0.015	0.0009	0.0003
R	-0.67	0.758	-0.031	0.015
I	1.07	0.38	0.0155	0.0079
Trend: restricted trend				
Number of obs: 444				

Note: results for the estimation of the 3 equation VEC model for the periods 1971m9-1983m1 and 1983m2-2020m1. Variables included are the growth rate of industrial production index ($\gamma_{ip,t}$), the real interest rate (R_t) and the monetary policy interest rate (I_t) and a trend and constant in the cointegration vector. 13 lags included.

the opposite. Notice that the findings in this table seem roughly consistent with the notion of inflation targeting that induce a large response of real interest rates to changes in nominal interest rates. Looking at the point estimates, an increase in the nominal (policy) interest rate pre-Volker requires a smaller increase in the real rate to restore equilibrium while it requires a larger increase in the real rate after for the sample after Volker (that is, the policy rate before Volker does not seem to have an associate increase in the real interest rate when increasing the nominal interest rate).

Table 6: Cointegration analysis with $y_t = \{\gamma_{ip,t}, R_t, I_t\}$

Cointegration vectors

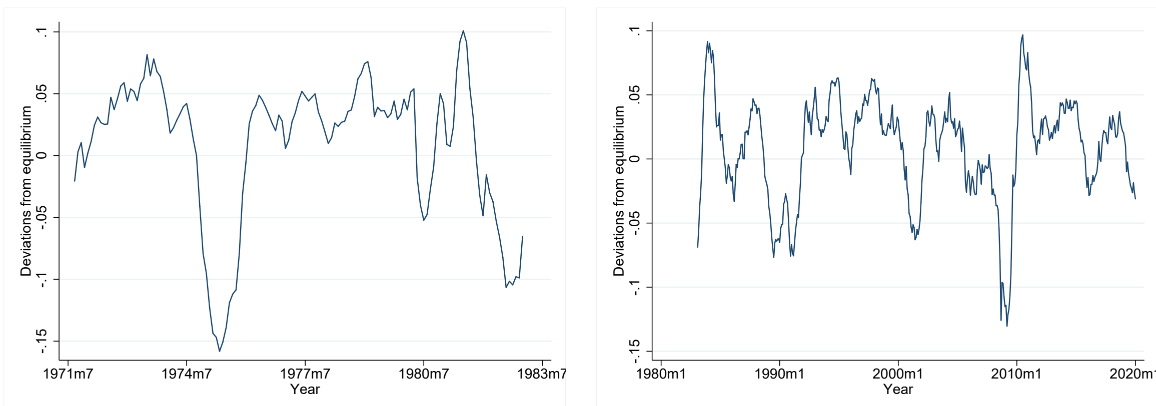
Coefficient	Value	Standard error	Value	Standard error
	1971m9-1983m1		1983m2-2020m1	
γ_{ip}	1	-	1	-
R	-0.0057	0.0019	0.012	0.007
I	0.00693	0.0014	-0.011	0.0044
Trend	0.000059	0.0001	0.00002	0.0001
Constant	-0.0734	-	-0.0058	-

Short run adjustment coefficients

Coefficient	Value	Standard error	Value	Standard error
	1971m9-1983m1		1983m2-2020m1	
γ_{ip}	-0.149	0.054	-0.01	0.013
R	-0.118	2.38	-1.19	0.63
I	15.29	3.82	1.12	0.32

Note: Estimates for the VEC model allowing for only 1 cointegrating vector for the periods 1971m9-1983m1 and 1983m2-2020m1. Variables included are the growth rate of industrial production index ($\gamma_{ip,t}$), the real interest rate (R_t) and the monetary policy interest rate (I_t) and a trend and constant in the cointegration vector. 13 lags included.

The second block in Table 6 presents the adjustment coefficient to the equilibrium relationship for each variable. These coefficients indicate which variables adjust when the cointegrating vector is not equal to zero, i.e. which variables adjust such that the system returns to equilibrium. As seen in the table, off-equilibrium during the inflationary regime, the real interest rate does not adjust as its coefficient is statistically zero at any significance level. Instead, both the policy and growth rates adjust. Instead, during the Volker disinflation the real and nominal interest rates seem to adjust (barely, in the case of the first one) rather than the IP growth.



(a) Great inflation period

(b) Post-Volker disinflation

Figure 6: Cointegrating relationships by sub-samples

Note: this figure presents the deviations from the eqilibrium condition of the VEC model with 1 cointegrating vector for subsamples 1971m9-1983m1 and 1983m2-2020m1. This is constructed using the point estimates of the cointegrating vector coefficients and observed data.

During the great inflation period, deviations from equilibrium seem to be corrected by an adjustment of the growth rate of IP index and changes in the interest rate. There is no adjustment of the real rate, suggesting that inflation follows closely the nominal rate in this sub-sample. This is consistent with a lax monetary policy regime, changes in the policy rate does not impact the real rates to the point of affecting consumption and investment decisions by the private sector. During the Volker disinflation we find the opposite behavior in the adjustment of variables to restore equilibrium where both the nominal and the real interest rates adjust, that is, changes in the monetary policy rate relate to changes in the real rate, this suggest that both the real rates and the inflation dynamics have changed in this sub-sample.

Figure 6 show the deviations from equilibrium for the two sub-samples. Interestingly, the different statistical features of the variables are reflected in these figures, for instance, notice that the deviations are more persistent during the great inflation period compare to the Volker disinflation. The size of the deviations is of similar magnitude in normal periods. The largest deviations, as expected, happen during times of crisis.

4 The Financial crisis

Lastly, one concern about the last set of results is that the world post-crisis has changed, the monetary policy based on interest rate management got into the ZLB very early and since 2007/2008 the monetary policy was mainly driven by an aggressive management of the liabilities of the central Bank. Moreover, the banking sector and international investors, as financial intermediary's trough which monetary policy impact investment and consumption decisions may have also changed their behavior.

From an econometric point of view, the Federal Funds Rate is I(0) from October 2008 onward while the real interest rate and the industrial production index growth are I(1). Yet, from the reasons discussed before we should not conclude that the real rate behavior in this period is detached from monetary policy choices. Instead, the nominal interest rate is not the appropriate monetary policy instrument in this period. The log of monetary base, seasonally adjusted, is I(1) so we can design the same three equation model as before with a new monetary policy instrument. This variable is a more appropriate instrument given the expansion of the balance sheet of the Federal Reserve Bank.

Table 7 presents the cointegration vector and short run adjustment coefficients for the post-Great Financial Crisis period. As can be seen in the table, there is a cointegration relationship between the variables and coefficients of the real interest rate and the monetary policy instrument are significant along that relationship. Moreover, it seems to be that, in contrast with the previous, non ZLB periods, the only variable that adjusts to deviations

Table 7: Cointegration analysis $y_t = \{\gamma_{ip,t}, R_t, M_t\}$, 2007m10-2020m1

Cointegration vectors		
Coefficient	Value	Standard error
γ_{ip}	1	-
R	.033	.005
M	-.042	.017
Trend	.0001	.0002
Constant	.59	-
Short run adjustment coefficients		
Coefficient	Value	Standard error
γ_{ip}	-.05	.03
R	-5.58	1.2
M	-.18	.105

Note: results for the estimation of the 3 equation VEC model for the period that followed the 2008 Financial Crisis, 2007m10-2020m1. Variables included are the growth rate of industrial production index ($\gamma_{ip,t}$), the real interest rate (R_t) and the log of the stock of monetary base (M_t) and a trend and constant in the cointegration vector. Number of lags 13.

from equilibrium is the real interest rate. The adjustment of monetary base is barely not significant at 5%.

The discussion in this and the previous sections suggests that monetary policy, both out and in the ZLB can excerpt strong impact on the real interest rate, in the short run as expected, but is also related to the real interest rate along the equilibrium.

5 Concluding remarks

In this paper we study monthly US data since early nineteen hundred, conditional on the existing monetary policy regime. We find that there seems to exist an equilibrium relationship, in terms of cointegration relationship, between the real interest rate, the monetary policy interest rate and real factors proxy by the average industrial production growth only after the end of the Bretton Woods: for the high inflation regime from 1971 to 1983 and during the Volker disinflation after 1983.

We find that this equilibrium vector is, however, not stable as it depends on the policy regime in place. In particular, there seems to be two different cointegration vectors for the period before the Volker disinflation, January 1983 and the period from February 1983 to January 2020. We find that along the equilibrium vector, real factors and monetary factors adjust differently. Moreover, during the inflation targeting period, there seems to be evidence of a tighter relationship between the real interest rate and the monetary instrument that seems to be absent during the Great inflation regime. Our results still hold after the financial crisis when we take into account the change in the relevant monetary policy instrument.

This report suggests the importance of monetary variables and regimes in the behavior of the real interest rate in the postwar US data.

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