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The Phillips curve and the inflation dynamics

Master Thesis Policy Economics

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To my family, who always supported me.

To all the people who accompanied me in this fantastic, challenging journey.

Thank you.

ABSTRACT

In this paper we examine the appropriateness of the adoption of the Phillips curve in order to predict changes in the inflation process. We proceed by modelling the Phillips curve framework adopting three different specifications. Our results provide evidence of the presence of a stable Phillips curve in the United States over a long period of time. In particular, all the three models adopted highlight an overall good dynamic tracking performance of the relative estimated Phillips curve in capturing the actual changes in the value of inflation. The underlying implications point out however that the Phillips curve slope has flatten over the time, resulting in a less sensitive inflation to labor market tensions. Moreover, our findings also suggests a situation where a more stable conduction of monetary policy pursued by the Federal Reserve in order to affect the future pattern of the level of inflation accentuates even more the flattening of the slope of the respective estimated Phillips curve.

Summary

1. INTRODUCTION

Phillips' (1958) article suggests many of the improvements made to the relationship between unemployment rate and inflation in the last 50 years. Most macro-econometric models during the 1970s were modelling the Phillips curve by estimating the following regression equation:
$\pi_t = \alpha_0 + \sum_{i=1}^{k} \alpha_1 \pi_{t-i} + \alpha_2 U_t + \epsilon_t$
where inflation π_t is a function of a constant α_0, the current value of the unemployment rate U_t representing a measure able to capture shocks in the labor market (Gordon, 2011), past values of inflation π_{t-i} reflecting the lags of the inflation response to monetary policy actions (Friedman, 1972)[1] and a disturbance term ϵ_t.

This *modus operandi*, however, was surrounded by considerable uncertainty, both theoretically and empirically, questioning the stability of the Phillips curve in the long-run and its usefulness in forecasting inflation dynamics for policy purposes. Economists such as Friedman and Phelps developed theoretical frameworks where expectations play an important role in shaping the level of inflation in the economy. In their view, the way how expectations about inflation were previously modeled[2] implied only a "particular path for inflation, depending on where it has been in the past, that does not depend on how vigorously or sluggishly monetary policy is pursuing its inflation target" (Fuhrer, 1995, p.45). Under this perspective, one of the most important critiques to the Phillips curve comes from the classical economist Robert E. Lucas that highlights the importance of changes in private agents' expectations with respect to changes in monetary and fiscal policies, and how those shifts in expectations are relevant in determining the stability of the Phillips curve in the long-run. Therefore, he points out the inappropriateness of the Phillips curve as an instrument for policy guidance because of its presumed non-sensitivity to those shifts in the underlying macroeconomic structure (Lucas, 1976).

As a consequence of the aforementioned various criticisms surrounding the Phillips curve framework at that time, already in the 1978, the Federal Reserve Bank of Boston economic conference was entitled "After the Phillips Curve", and many of the academic researchers in this conference were referring to an already poor and inefficient Phillips Curve that was not anymore recognized as a valid instrument to forecast inflation (Fuhrer, 1995). Moreover, the prevalence of these thoughts regarding the inappropriateness of the Phillips curve as an instrument of policy guidance was even more accentuated by a situation in which major supply shocks were hitting the United States economy.

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[1] In this traditional view of the Phillips curve, current inflation equalizes expected inflation in the long-run when the sum of the coefficient α_1 on the lagged values of inflation is equal to unity.

[2] Espressing the expected value of inflation by using only its past values (lags) in the Phillips curve equation.

Even after the already proclaimed death of the Phillips curve, many economists successively still considered the macroeconomic relationship underlying the Phillips curve an important concept that can be exploited as an instrument of policy guidance in order to capture and understand inflation dynamics. In fact, under the light of the worst global financial crisis and economic downturn since the Great Depression in the United States, the relevance of the Phillips curve has retuned back as a central topic in order to examining enduring macro and monetary policy questions, as the Federal Reserve Bank of Boston conference in 2008 was entitled "Understanding Inflation and the Implications for Monetary Policy: A Phillips Curve Retrospective."

After the slow recovery from the financial crisis, The United States' economic growth has picked-up, as unemployment rate has fallen since 2009 and it's now stable around the 4 per cent, while inflation has run persistently below its target level of 2 per cent. Even during the current situation of economic expansion, the role of the Phillips curve in understanding inflation dynamics have been questioned, again. The main reason lies in the fact that with the current low unemployment rate we are not seeing higher inflation. As the Federal Reserve Chairman Jerome H. Powell pointed out during his speech "The Outlook for the U.S. economy" in April 2018, the link between labor market tensions and changes in inflation has become weaker and more difficult to estimate during the last two decades, reflecting a flattening of the Phillips curve slope (Kuttner and Robinson, 2010). Moreover, many members of the Federal Reserve Open Market Committee and policy-makers also noted that other factors such as inflation expectations and transitory changes in import prices are important determinants of inflation that could potentially undermine the relationship between inflation and unemployment rate.

Therefore, under this perspective, we are left with the following research question:

Is the Phillips curve still appropriate in capturing inflation dynamics in the United States?

Answering this research question is important in the determination of the appropriateness of using the Phillips curve equation in order to capture fluctuations and developments of the inflation process (ECB, 2014).

Moreover, what differentiate this thesis from other similar academic researches is the investigation on the stability of the Phillips curve not only in the past periods, but also investigating in the stability of the Phillips curve during the current U.S. economy situation, after the recently policy economic developments.

In order to do this we estimate three different Phillips curve equation models for the United States of America, analyzing the relative dynamic tracking performances and stability over a very long time period that range from the second quarter of 1949 to the last quarter of 2017. We have chosen the Unites states because the U.S. economy is still recognized as an important benchmark for many western-European countries under many economic aspects.

As already mentioned, in order to predict changes in inflation for the entire sample period, we adopt three Phillips curve single-equation models: a "triangle-model" of the Phillips curve, a modified version of the traditional model, and a hybrid form of the Phillips curve.

The first model reflects our base specification model that incorporates shocks in the labor market captured by the unemployment rate, shocks in the supply side captured by the price of imports and shocks to inflation captured by the last year values of inflation. The second model is a modified version of the base specification model that replace the unemployment rate with the labor share of income in order to test the effect of a different measure of economic slack on inflation in the Phillips curve equation. The third model instead differ from the base specification model because it includes a forward looking inflation components in the equation.

In order to estimate the "triangle-model" Phillips curve equation, we use historical macro-data on the annual Consumer Price Index inflation excluding food and energy (core CPI inflation) as a measure of the consumer price levels in the economy, and the civilian unemployment rate as a measure of economic slack that captures demand shocks in the labor market. Moreover, we use historical data on the average percentage change in the import prices of all commodities in the United States as a measure that is able to capture supply shocks.

For the modified version of the traditional model we replace unemployment rate with firms' real marginal cost of labor proxied by historical data on the labor share of income in the nonfarm sector, representing a measure of labor market slack in this model that is able to capture demand shocks in the labor market.

Regarding the hybrid Phillips curve, instead, we only slightly change the "triangle-model" by including forward-looking component of the inflation rate proxied by historical data on the change in private agents expectations about next year inflation, surveyed by the Michigan University Research Center.

The thesis proceeds as follows. Section 2 provides an overview of the existing theoretical and empirical developments related to the Phillips curve during the history. Section 3 describes the data employed in order to conduct the empirical strategy. Section 4 provides the three empirical strategies conducted in order to predict the actual core CPI inflation dynamics for the US economy, analyzing the main findings and results respectively. Section 5 represents the conclusion.

2. LITERATURE REVIEW

Back to the origins

A.W. Phillips was the first economist to find a negative relationship between unemployment and the rate of change of money wage rate[3]. In Phillips' (1958) article, the principle of the excess of demand in the labor market represents the first and main determinant factor that links the changes in price of labor services and unemployment. When there is an excess of demand for a good or a service relatively to its supply, we can expect the price to rise and, contrarily, if there is a deficiency of demand of that good or service relatively to the supply of it, the price falls. Intuitively, this principle can be translated into a wage inflation-unemployment trade-off. Therefore, when the demand for labor is high and there are few unemployed in the economy, employers are tempted to offer wages slightly above the prevailing rate due to the scarcity of labor force and in order to attract qualified labor from other competitors. On the other hand, a situation where the demand of labor is low and there are more unemployed in the economy implies that workers are not willing to agree wages under a certain prevailing rate. Hence, the price of labor services falls, but only at a very slow pace due to workers' resistance to wage reductions.

Looking at the aforementioned dynamics from the workers perspective, instead, Phillips notes that in moments of economic expansion where demand for labor is increasing and the percentage of unemployment is low, workers can impose a certain degree of pressure to firms[4] in order to obtain higher wages with respect to a situation of economic contraction where employers are clearly not willing to offer higher wages. Consequently, in this case, workers reverse in a weaker position in which they are not able to impose pressure to employers for higher salaries requests.

From the aforementioned theoretical background, a specification model for the Phillips curve was born.

The original "wage-price" specification equation model used by Phillips is the following:

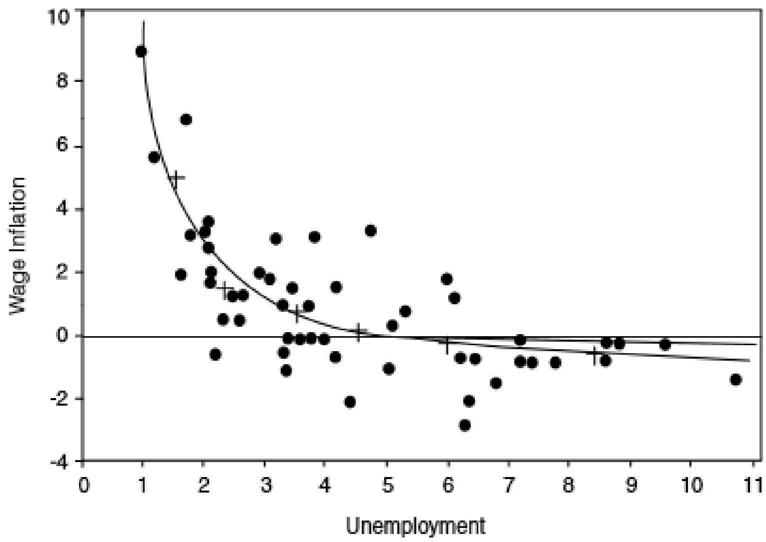
$$w_t = \alpha_0 + \beta_1 U_t + \epsilon_t$$

[3] According to Phillips (1958) the term can refers also to wage inflation and/or price of labor services.
[4] Even through the power of labor unions.

where the rate of change in nominal wage rate w_t depends on a constant α_0, and the current value of the unemployment rate U_t and an error term ϵ_t.

The corresponding fitted values estimated through least squares method have been translated into an unemployment–wage inflation relationship, as reported in Figure 1 below. The curve implies that very high values of unemployment could lead to very low wage-inflation and very low values of unemployment could lead to very high wage-inflation (King, 2008).

Figure 1. The negative relationship between wage-inflation and unemployment rate



Source: (King, 2008).

Note: This is the scatter diagram from Phillips (1958) showing negative relationship between unemployment and wage inflation over 1861-1913 period in the UK. The dots represents annual observations while the crosses represent trade cycle averages.

The Phillips curve becomes "famous"

Samuelson and Solow's (1960) article mainly contributed to the introduction of the Phillips curve term in the macroeconomic language that subsequently became an important macro econometric equation during the research activities conducted over the 1960s period. Samuelson and Solow decided to hand-draw the yearly percentage changes of average hourly earnings in manufacturing sector in the U.S. against the annual average percentage of the labor force unemployed, successively translating this plot into the Phillips' diagram, as displayed in figure 1 above. This diagram shows the "American pattern of wage increase against degree of unemployment into a related diagram showing the different levels of unemployment that would be needed for each degree of price level change" (Samuelson and Solow, 1960, p.192). The Phillips curve that they hand-drew for the United States in order to fit the data from the 1934-1958 period provides the same negative tradeoff between wage-inflation and unemployment rate as suggested by the results of Professor Phillips. The only exceptions came from the absence of a stable trade-off for the 1930s and a positive relationship between inflation and unemployment from the pre-war years towards the 1950s (Gordon, 2011). However, the authors argue that the upward shift in the Phillips curve during the post-war period is due to the presence of less efficient trade unions and a less flexible labor market in US, compared to the UK counterpart.

The natural rate hypothesis and the role of expectations

Throughout the period ranging from the mid-1960s to the late 1970s, monetary policy was active in the fact that the Federal Reserve Bank was pursuing its inflation and unemployment targets based on the trade-off implied by the Phillips curve framework (Hetzel, 2013). The Samuelson and Solow Phillips curve, coming in as it did during the recession of 1960-1961, provided breeding ground for policymakers in adopting expansionary monetary and fiscal policies in order to raise the level of inflation in favor of a lower unemployment (Hall and Hart, 2012). This turned out to contribute to a period of hyperinflation in the US economy[5] occurred during the late 1960s and the 1970s, raising concerns regarding the stability of the Phillips curve over long periods of time.

Friedman (1968) was one of the first economists that questioned the stability of the Phillips curve in the long-run. He assumed that in a situation of economic expansion, the level of prices in the economy raise before wages, as firms increase wages at a lower rate with respect to the price levels, thus decreasing the real wages perceived by the labor force. This situation will inevitably lead to the raise in the demand for higher nominal wages by the workers as they realized that their purchasing power has effectively decreased (Samuelson et al., 2009). Consequently, there will be a raise in the wage rates in order to equate the raise in the price

[5] Quarterly rates of change of the CPI inflation in 1968 and 1969 are the highest for any postwar year since 1951 (Gordon, 1970).

levels and the correspondent increase in real wages will lead unemployment back to its "natural" rate[6] (the natural rate hypothesis).
Friedman's insight in the context of the Phillips curve is that the creation of money by central banks doesn't influence the real economy and hence employment in the long-term, due to the fact that any increase in the supply of money would be offset by a proportional rise in the level of prices and wages. Considering this perspective, monetary policy that aims to lower unemployment levels through the adoption of expansionary policies can achieve this target only in the short-term, implying a vertical Phillips curve in the long-run.
Friedman (1968) also suggested that conventional analysis of the Phillips curve ignored the adjustment of private agents' expectations with respect to inflation. He assumed that employers always correctly adjust their expectations with respect to inflation while on the demand side workers respond with a certain delay to changes in the overall actual level of prices. This framework implies the same situation implied in the natural rate hypothesis: in a period of economic expansion, firms increase wages at a lower rate with respect to the price levels, thus reducing real wages. In this way, due to the fact that workers fail to adjust their expectations with respect to the actual price levels, they "accept" changes in the nominal wages as real, despite their overall purchasing power remained stable ("money illusion"). However, according to Gordon (2011), Friedman's suggestion doesn't reflect solid theoretical foundations, simply due to the fact that workers can adjust their expectations by observing the level of actual prices in the economy through their ordinary private consumption.

Gordon's critique also applies to the theory developed by Phelps (1967). In his theoretical setting, workers don't receive information regarding the rest of the economy and employers don't adjust their expectations to inflation. Consequently, when both demand and supply sides are equally fooled and expectations are incorrect, if there is a raise in inflation, both economic agents will increase their respective productivity by working more, being unaware that price levels increased also in the rest of the economy. All firms will raise wage rates contemporaneously and by the same amount, thus creating a situation where there will be no frictional unemployment[7]. Therefore, a decrease in the unemployment rate will occur even though all the firms in the economy, unconsciously, have increased contemporaneously wage rates by the same amount. As a result, there will be a negative tradeoff between wage inflation

[6] "The rate of unemployment at which the rate of change of nominal wages equals the expected change in the overall price level" (Fuhrer, 1995, p.42).
[7] Intuitively, in a situation where workers face their own firm raising wages, they will decide to remain in the same company instead of quit and looking for other better paid jobs.

and unemployment rate only in the short-run, as long as expectations are incorrect (Gordon, 2011).

Lucas' critique

Both views from Friedman and Phelps in their respective models have a strong assumption: imperfect information. Soon thereafter, one of the most important critiques to the Phillips curve came from the classical economist Robert E. Lucas, Jr. He suggests a second assumption in addition to the assumption already mentioned above: rational expectations. This assumption implies that economic agents such as firms and workers don't repeat errors over time in adjusting their expectations but they use the knowledge acquired in the past to adopt correct actions for the future (Lucas, 1972).

Lucas' insight in the context of the Phillips curve is based on the fact that expectations of economic agents such as firms and workers are based upon other economic agents' behaviors such as monetary policymakers decisions (Fuhrer, 1995). As a consequence, the Phillips curve might not be stable in the occurrence of major policy changes mainly due to its lack of micro foundations (Lucas, 1976).

Lucas and Sargent (1979) also strongly criticize the use of the Phillips curve as an instrument for policy guidance, mostly when used in Keynesian macroeconomic models. They suggest that these models were using "poor" econometric techniques as for instance modelling expected inflation as a function only of its past values. They argue that this inflation forecast can be reasonable only in the short-run and when monetary policy has remained relatively stable over time (Fuhrer, 1995).

Later on, however, Fuhrer (1995) assesses the Friedman-Phelps views regarding the role of expectations and, by implication, the validity of the Lucas' critique in the context of the Phillips curve framework. He analyzed the stability of the Phillips curve during the period of one of the major monetary policy changes in the United States: the Volcker disinflation program occurred during the early 80s. He estimated the following "price-price" Phillips curve equation model:

$$\Delta p_t = \sum_{i=1}^{12} \alpha_i \Delta p_{t-i} + \sum_{j=1}^{2} \beta_j U_{t-j} + \gamma \Delta po_t + \epsilon_t$$

where Δp_t represents the core CPI inflation, Δp_{t-i} indicates the changes in the lagged value of the core CPI inflation whose coefficient α_i is constrained to one in order to equalize expected inflation in the long-run, U_{t-j} denotes last quarter value of the unemployment rate, Δpo_t is the change in the oil prices and the last term is the error term.

After estimating this Phillips curve equation, he tested the probability of possible shifts in the estimated coefficients during the 1978-1983 period performing a Chow breakpoint test. The results of this test clearly show instead stable estimated coefficients that don't shifts in the occurrence of the monetary policy change. Thus, this finding provides strong evidence against the fact that shifts in private agents' expectations caused by policy changes destabilize the Phillips curve over time.

A "triangle – model" for the Phillips curve

During mid-1970s and early 1980s, the United States economy was facing a positive relationship between inflation and unemployment rate (as reported in Figure 3 at page 16). During this period there was a return, as a theoretical background, of the economic Keynesian thought that explicitly incorporated demand and supply shocks in the Phillips curve model equation[8], with lagged values of inflation as a reflection of the general inertia that was characterizing the US inflation process in that period.

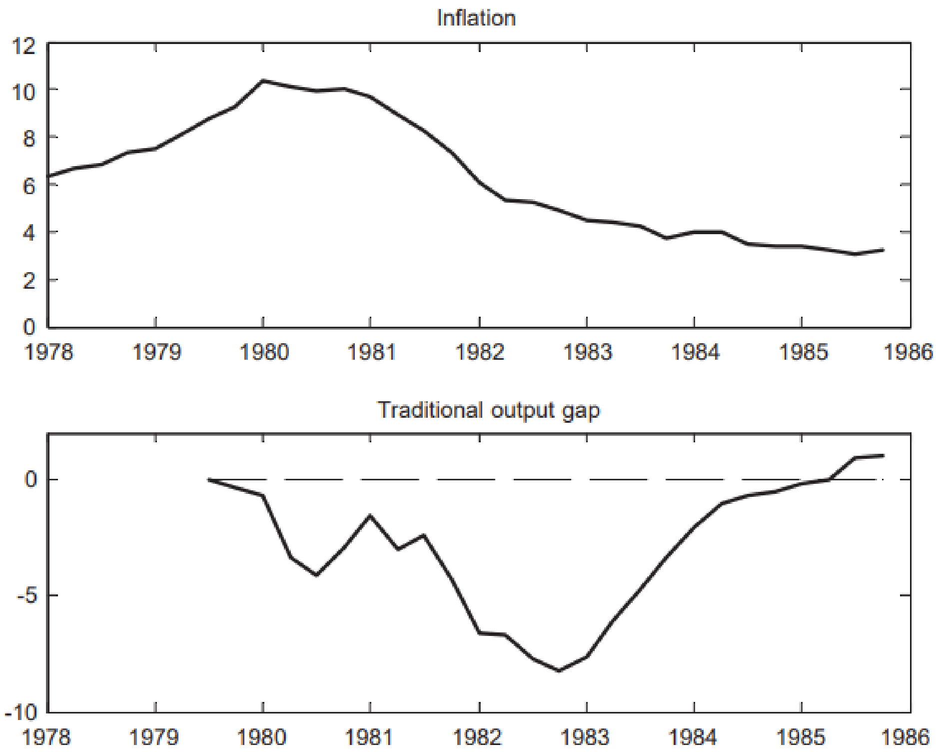
In this "pure" backward-looking Phillips curve, demand shocks are measured by output gap, the unemployment rate or unemployment gap (difference between the unemployment rate and its natural rate) and real marginal costs (proxied by the labour's share in national income[9]). The supply shocks, instead, are measured by changes in the relative price of food, energy and imports, and changes in the trend growth of productivity.

Therefore, as a main consequence of the oil price shocks that were hitting the US economy during this period, Gordon (1975) and Phelps (1978) recognize the importance of including aggregate demand and supply shocks in the Phillips curve equation. Gordon (1977b) suggests the use of a "triangle model" in order to forecast inflation, with the inclusion of supply and demand shocks and backward-looking components for inflation into the Phillips curve

[8] Mostly because of the occurrence of major supply shocks that were hitting the U.S. economy at that time.
[9] Calculated by dividing real wages by average product of labor.

equation. Successively, empirical evidence from King et al. (1982) also suggests the use of the "triangle model" in a vector autoregressive model (VAR) in order to forecast the speed at which inflation adjusts in response to high unemployment and low output ("sacrifice ratio")[10] during the Volcker disinflation program of 1979–1986 period in US. The authors add also the exchange rate variable into the inflation equation in order to account for the short-run inflation adjustment process[11]. He found that in order to achieve a long-run reduction in the inflation rate by 5 percentage points through the use of a contractionary monetary policy, the United States woud need to reduce output by 29 percentage points of the annual GDP (roughly a thousand billions of dollars). However, the prediction of King et al. (1982) didn't occur in reality. In fact, as we can see below from figure 2, in order to achieve a reduction of 5 per cent in inflation the reduction in the annual GDP has been of roughly 9 per cent during the 1980-1983 period.

Figure 2. Inflation and output gap during the 1978-1986 period in US



Source: Goodfriend and King (2005, p.984).

Empirical evidence from Blinder and Rudd (2008) also suggests that the inclusion of supply shock in the Phillips curve is of crucial importance. They assess the validity of the classic

[10] The "sacrifice ratio" denotes the total loss in output, measured as a percent of GDP, associated with a 1 per cent permanent reduction in inflation.
[11] The adjustments process result from the mix of monetary and fiscal policies effects on the exchange rates.

supply-shock explanation by using a vector autoregressive model that includes a "triangle-model" specification for the Phillips curve, correctly forecasting the level of the core CPI inflation during 1972-1983 period in US.

Empirical evidence from Fuhrer (1995) again suggests the inclusion of oils prices as a control variable[12] in a "triangle-model" Phillips curve equation estimated by least squares method with backward-looking inflation components[13] and the inclusion of two lags of unemployment rate in order to predict inflation dynamics. The corresponding dynamics tracking performance of the estimated core CPI inflation clearly show that it can predicts really well its actual value over a long period of time in the US (1960-1993).

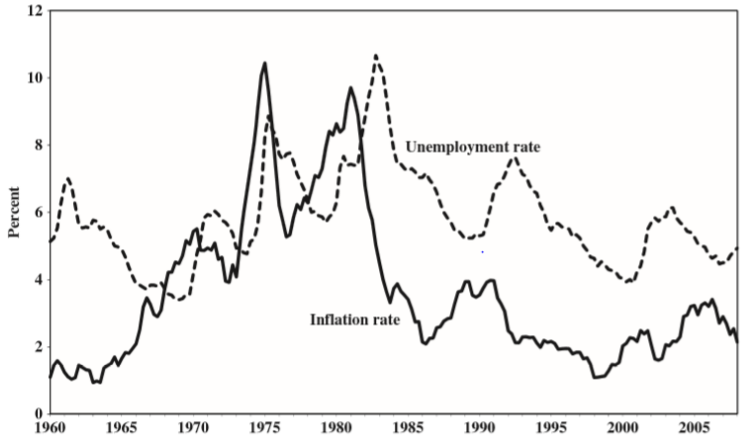
Empirical evidence from Lown and Rich (1997) also highlights the usefulness of using a traditional backward-looking price-inflation Phillips curve equation that embodies the "triangle-model" of the Phillips curve in order to forecast consumer price inflation. They estimate the following regression:

$$\Delta p_t = \alpha_0 + \alpha_1 \Delta outp_{t-1} + \alpha_2 \Delta po_t + \sum_{i=1}^{3} \alpha_3 p_{t-i} + e_t$$

where $\Delta p_t$is the core CPI inflation that depends on a constant α_0, the first difference of the output gap in the last quarter $\Delta outp_{t-1}$, the net positive change in the real price of oil Δpo_t that acts as a control variable, lagged values of the core CPI inflation p_{t-i} and an error term e_t. The results estimated by the Ordinary Least Squares method provides a good tracking performance of the core CPI inflation in predicting its actual value over the 1965-96 period in US, with the only exception of a break-down after the 1993. The authors then slightly modified the price-inflation Phillips curve equation by adding as an explanatory variable the growth rate of unit labor costs in the nonfarm business. As a results, they arrive to the conclusion that the break-down of the Philips curve during the period 1993-96 was due to the slowdown in compensation growth during the early 1990s, thus founding a better dynamic tracking performance of inflation over the entire sample period.

[12] Mainly due to the oil shock during the 1970s.
[13] Following Fuhrer (1995), the sum of the coefficients on lagged inflation should be normally constrained to one in order to equal inflation and its expected value in the long-run.

Figure 3. The path of the inflation and unemployment rate in US over the 1960-2007 period



Source: Gordon (2011, p.15).

Note: Quarterly data on unemployment and inflation rates.

A "pure" forward-looking model for the Phillips curve

During the 1980s, a new Keynesian Phillips curve (NKPC) approach took hold in order to evaluate monetary policy and analyze inflation dynamics, with a theoretical background based on new Keynesian theory of monopolistically competitive firms with market power (Gordon, 2011) that face constraints on price adjustments.

According to Roberts (1995), microeconomic foundations of prices that fail to adjust due to changes in the broad economy are an important part of the new Keynesian economics and in the determination of monetary models of business cycle. Moreover, as Blanchard (1986) points out, the central notion in the Keynesian interpretation of the economic fluctuations that serves as a theoretical background for the Phillips curve is that prices are "sticky". In this context, the model developed by Calvo (1983) have a fundamental importance.

Calvo (1983) suggests the use of a random price adjustment model with the underlying key assumption that nominal individual prices are not subject to repeated revisions by firms in the economy. The reason lies in the fact that "individual price-setters are assumed to set their prices taking into account the expected average price and the state of the market (given by the excess demand) during the relevant future" (Calvo, 1983, p. 383). In this framework, the author uses an equation for firms' desired price as a function of the overall price level (weighted average of all prices firms have settled in the past) and the deviation of unemployment from its natural rate[14]. Due to the fact that firms don't adjust their prices frequently, the author models another equation for the price adjustment decision as a function of a weighted average of current and future desired prices. As a result of this theoretical effort, a new Keynesian Phillips curve equation was born. The NKPC equation is the following:

$$\pi_t = E_t\pi_{t+1} + (U_t - U^*)$$

where the current inflation rate π_t is a function of expected inflation for the next period $E_t\pi_{t+1}$ and the deviation of unemployment from its natural rate $(U_t - U^*)$. By implication, in this "pure" forward-looking NKPC framework, "monetary policy can affect inflation through the management of inflation expectations" (Mavroeidis et al. 2014, p. 127).

Empirical evidence from Roberts (1995) suggests the use of the "pure" forward-looking NKPC with the inclusion of supply shocks in order to forecast inflation. He proxied expected inflation by using three different surveys[15] related to economic agents' expectation regarding future dynamics of the annual percent change in the consumer price index. He estimated two NKPC equations: one states the core CPI inflation as a function of a detrended output (as the percent deviation of real GDP from a deterministic trend) and expected inflation[16]. The other one, instead, replaces the detrended output by the unemployment rate. Applying the OLS method he found a positive relationship between output and inflation while a negative relationship between unemployment rate and inflation for the 1949-1990 period in US, suggesting a structurally stable "pure" forward-looking NKPC.

A hybrid model for the Phillips curve

Due to the aforementioned continuous disagreements surrounding the theoretical framework of the Phillips curve, during the late 1990s a hybrid form of the New Keynesian Phillips was conceived in order to forecasts and understands inflation dynamics. The hybrid NKPC curve equation suggests the use of both backward and forward-looking components of inflation and

[14] Considered as a Nash equilibrium where each firms want to charge the same prices that other firms are charging in the economy (Mankiw, 2001).
[15] Michigan, Livingston and McCallum surveys.
[16] He also uses the real price of crude oil as an instrumental variable in order to avoid an eventual correlation between the disturbance term and output.

demand shocks such as unemployment rate, output gap and real marginal costs as a main determinants of the level of prices in the economy.

Empirical evidence from Galì and Gertler (1999) suggests then the use of a hybrid NKPC equation in a structural model that exploits a non-linear instrumental variable generalized method of moments (GMM) estimator in order to forecast inflation. They use the staggered price model from Calvo (1983) as a theoretical background, estimating a Phillips curve equation where the inflation rate depends on firms' marginal costs (proxied by the labor share of income), lagged values of inflation in order to capture price inertia and the expected future inflation as a measure of the forward- looking price setters' expectations about the future level of inflation. The corresponding results show a NKPC equation that approximates well the US inflation dynamics over the 1960-1997 period. Moreover, they found that the coefficients on expected inflation (ranging from 0.59 to 0.87) remains dominant due to the fact that weight on one quarter lagged value of inflation is small (which ranges from 0.085 to 0.383) and coefficients on additional lags of inflation result to be insignificant.

Following Galì and Gertler (1999), empirical evidence from Dupuis (2004) also tests the validity of the hybrid NKPC by using a non-linear instrumental variables (generalized method of moments) approach in order to forecast the Price Consumer Index inflation over the second quarter of 1972 to the second quarter of 2003 for the United States. He estimates two models of the hybrid Phillips curve. The first model uses marginal costs measured by the logarithm of the labor share of income in the non-farm business sector as a main driving force of inflation, while in the second model he uses eight lags of output gap as a main determinant of inflation. The instrument set includes in both models four lags of inflation in order to capture inflation persistence. The corresponding findings are in line with theory, resulting in statistically significant positive signs for each variables included in both models: an increase in marginal cost by one percentage points led to an increase by 0.23% in inflation, while an increase by one percentage points in output gap raise inflation by 0.05%. Moreover, the estimated degrees of backward-looking behaviors in price setting is 0.35 and 0.5 in the marginal costs and output-gap models respectively which suggested that 35 per cent and 50 per cent of firms were using backward-looking price setting rules in the respective models (Dupuis, 2004).

Furthermore, empirical evidence from Mehra (2004) suggests the use of a hybrid form of the Phillips curve, assuming private agents' rational expectations with respect to future inflation and including lagged values of import prices as a further explanatory variable in order to capture supply shocks in the economy. The author uses an instrumental variable approach[17], estimating through OLS the following hybrid Phillips curve model:

$$gdp\pi_t = c + \sum_{i=1}^{4} \alpha_i gdp\pi_{t-i} + \varphi_p gdp\pi_t^e + \sum_{j=1}^{2} \gamma_k po_{t-j} + \beta_v outp_t + e_t$$

where the current inflation rate $gdp\pi_t$ (measured by the behavior of the chain-weighted GDP deflator) is a function of a constant c , the four lagged values of inflation $\sum_{i=1}^{4} gdp\pi_{t-i}$, one lead of expected inflation $gdp\pi_t^e$, two lagged values of import prices $\sum_{j=1}^{2} po_{t-j}$, the contemporaneous value of output gap $outp_t$ and a disturbance term e_t. The author found that the hybrid specification model predict inflation quite well in two different subsamples in the United States: the first subsample that range the first quarter of 1961 to the last quarter of 1997 and the second one that range from the first quarter of 1961 to the second quarter of 2003. He also found out that lagged values of inflation move almost one-to-one with current inflation, denoting a high level of persistency. Moreover, the coefficients on import prices enter significantly in the hybrid specification model. He concludes with the remark that expected future inflation is not the major driving force of current inflation, thus in contrast to Galì and Gertler's (1999) findings.

Therefore, a hybrid form of the New Keynesian Phillips curve has demonstrated to be another valid tool for policies guidance in the hands of policymakers that can be adopted in order to understand inflation dynamics until recent times. Furthermore, it results in a good compromise between both "pure" backward-looking and the "pure" forward-looking Phillips curve models respectively.

Flattening of the Phillips curve slope

As we have already mentioned in the introduction, during the last two decades it has been observed by many policy makers and economists that the tradeoff between inflation and economic slack has become flattened (Razin and Binyamini, 2007).

Seydl and Spittler (2016) suggest that one reasonable explanation is the high degree of openness that characterizes the United States economy, where the higher international competitiveness

[17] Where the instrument used are constant: change in federal funds rate, change in import prices, change in output gap variables, four lagged values of inflation rate and change in current nominal defense expenditures.

among firms leads to shifts in the U.S. output away from domestic production (as for instance for the manufacturing production) toward foreign emerging market countries, reducing the influence that the labor market has on the determination of goods prices. Consequently, this leads to a situation where U.S. workers seek for jobs opportunities in low-wage domestic service sectors, implying a further decrease of their bargaining power as an instrument to obtain higher wages. Therefore, foreign labor costs also have a substantial influence on the pricing of many imported goods and goods consumed domestically, implicitly leading to a flattening of the Phillips curve slope. This turns out to implicitly assume a weaker effect of tightening labor market conditions on the price levels.

Furthermore, in a situation of lower and less responsive inflation on the channel in which firms change their prices, Mishkin (2007) points out that during a period of low-inflation, firms may also decide to keep their price fixed for longer periods at lower costs, thus letting the inflation be less reactive to transitory labor market shocks. In this fashion, monetary policy could affect the slope of the Phillips curve without having affected the way in which relative expectations are formed (Mishkin, 2007). Under this perspective, Ball and Mazumder (2015) suggest a further plausible explanations for a flattened Phillips curve slope that might come to the increased anchoring of inflations expectations held by agents in the economy due to the more predictable monetary policy pursued by the FED in order to stabilize price inflation and the level of employment in the economy.

Consequently, under these different propositions regarding the recent flattening of the Phillips curve slope, additional applied researches on the topic seem to urge in order to better understand the mystery that surrounds the dynamics between inflation and economic slack and the consequent macroeconomic and policy implications.

Therefore, in the following section we present three different models of the Phillips curve in order to capture core CPI inflation dynamics in the United States over the period that ranges from the second quarter of 1949 to the last quarter of 2017.

The first specification is a “triangle-model” Phillips curve and represents our base specification model, the second one is a modified version of the aforementioned model that replaces unemployment rate with labor share income as a main driving force of inflation, and the third one is denoted by a hybrid Phillips curve model that explicitly incorporates a measure of expectations about inflation. The primary aim is therefore to investigate in the appropriateness of the Phillips curve in explaining changes in the inflation process under different assumptions, while the secondary purpose is to test the stability of the estimated Phillips curve under these different propositions. In this fashion, our intent is to provide insights that can be helpful to better understand which factors are representing the main determinants of inflation today and which role they play in the context of the Phillips curve.

3. DATA

In order to measure the inflation rate, we collected data regarding the quarterly seasonally adjusted price indexes of personal consumption expenditures of all items excluding food and energy from the U.S. Bureau of Economic Analysis. Then, we calculated the Consumer Price Index or "core CPI" inflation as follows:

$$Annual\ Core\ CPI\ inflation = 100 * \left(\frac{Price\ index\ PCE}{Price\ index\ PCE_{-4}} - 1\right)$$

Where the denominator of the ratio indicates the price index of the Personal Consumption Expenditures excluding food and energy in the last year (four quarters). In this way we were able to obtain the annual Core CPI inflation. We choose the core CPI inflation because it is the most monitored measure of inflation by economists. Moreover, it doesn't consider food and energy because of their relative volatile prices. We also collected data regarding expectation about inflation. We measured expected inflation rate by the median expected price change of the next 12 months that comes from the Surveys of Consumers conducted by the Michigan Survey Research Center. The Michigan Survey Research Center, in its periodic surveys of consumer attitudes, asks individuals what they expect inflation to be over the coming years, thus providing a reliable measure for how expectations about future prices levels will be in the future. The relative time series range from the second quarter of 1978 to the third quarter of 2017[18]. In order to measure the unemployment rate, we collected data regarding the quarterly seasonally adjusted civilian unemployment rate from the U.S. Bureau of Labor Statistics. The unemployment rate has been measured as the percentage of the civilian labor force[19]. The labor force data were restricted to people from individuals of age 16 years and older who currently reside in the US. For both measures of core CPI inflation rate and unemployment rate the time series start from the first quarter of the 1948 until the last quarter of 2017. As an alternative measures of economic activity, we collected quarterly data regarding the seasonally adjusted percentage change in output gap calculated from the U.S. Bureau of Economic Analysis with relative time series that range from the first quarter of 1947 until the last quarter of 2017. Moreover, we acquired data on the quarterly seasonally adjusted percentage change index that refers to the labor share income in the nonfarm business sector from the U.S. Bureau of Labor

[18] The time series starts only from the second quarter of 1978 due to unavailability of previous data.
[19] Also defined as the U-3 measure of labor underutilization.

Statistics. The correspondent time series start from the first quarter of the 1947 until the last quarter of 2017. Finally, we collected data regarding the average percentage change in price of imports index that comes from the U.S. Bureau of Economic Analysis. The quarterly average percentage change of the import price index refers to all the commodities imported in the US and the relative time series range from the first quarter of the 1947 to the last quarter of the 2017.

4. *EMPIRICAL FRAMEWORK*

4.1 A "TRIANGLE-MODEL" PHILLIPS CURVE

In order to forecast the actual core CPI inflation rate in the United States, we employ a "triangle-model" Phillips curve. Therefore, the base specification model is given by:

$$\Delta\pi_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \Delta\pi_{t-i} + \sum_{j=1}^{2} \beta_j U_{t-j} + \sum_{k=1}^{4} \gamma_k \Delta p_{t-k} + \epsilon_t$$

where α_0 represents the constant, π_t indicates the annual core CPI inflation, π_{t-i} denotes the lag of annual core CPI inflation, U_{t-j} indicates the lagged value of the civilian unemployment rate, p_t represents the price of imports index and the final term denotes the disturbance term.
Before estimating our Phillips curve model, we conduct an Augmented Dickey-Fuller test statistic to test whether the time series that refers to our endogenous variables follow a unit root process or not[20]. In particular, the conduction of this test is important in order to prevent possible issues of having a spurious regression model. The results of the Augmented Dickey-Fuller test statistic indicates that every variable[21] in our regression model follows a stationary process after first differencing (Δ), therefore implicitly following an ARMA process[22].
According to Fuhrer (1995), the sum of the coefficients on the two lagged values of the unemployment rate can be interpreted as the "level of unemployment effect", while the coefficient on the second lag as a "speed limit" effect. In fact, if $aU_{t-1} + bU_{t-2}$ represents the unemployment contribution to our "triangle-model" Phillips curve, then, $aU_{t-1} + bU_{t-2}$ can also be represented by $(a+b)U_{t-1} - b\Delta U_{t-2}$ where the first term indicates the level effect while the second term denotes the change effect or "speed limit" effect (Fuhrer, 1995).
The level effect gives us a measure of the general effect of unemployment rate on inflation, while the speed limit effect captures larger changes in inflation, for a given level of unemployment rate, due to more rapid changes in unemployment rate (Fuhrer, 1995).

[20] The correspondent ADF tests are displayed in the appendix (tables 14-15-16-17-18).
[21] Excluded the unemployment rate and the constant, where the former is stationary in level at 1 per cent significance level.
[22] The autoregressive-moving average model is composed by an autoregressive part (AR) that regress the variable on its own lagged values and a moving average part (MA) that model the error term as a linear combination of the errors terms occurring at the same moment and at different times in the past.

We expect the sum of the coefficients on the unemployment rate to be negative, as indicated in table 1 below.

The four lagged values of the annual core CPI inflation rate incorporate inflation persistency, capturing the dynamics of price adjustments related to expectations formation as well as to wages and prices contracts (Lown and Rich, 1997). Therefore, in this equation model, price inertia and inflation expectations are assumed to be incorporated in the inflation rates observed in the last year, as indicated by the sum on the four quarters values of π_{t-i}. Furthermore, we expect the sum of the last year value of inflation to be positive, as indicated in table 1 below.

The price of imports has been included in order to capture supply shocks in the economy.[23] We expect the sum of the relative four lagged values coefficients to be positive (as reported in table 1), because higher price of final consumption goods imports leads to higher price levels in the economy and higher prices of intermediate goods lead to higher firms' marginal costs and hence higher inflation.

Therefore, our base specification model embodies a "triangle-model" of the Phillips curve that include backward-looking components of inflation measured by the past year value of the annual core CPI inflation, capturing inflation persistency and representing a proxy for inflation expectations held by private agents in the economy; demand shocks in the labor market captured by the unemployment rate, and supply shocks captured by the price of imports. This set of explanatory variables is meant to capture changes in the core CPI inflation.

Table 1. List of our indipendent variables and corresponding expected signs

Independent variable	Expected sign based on literature
π_{t-i}	+
U_{t-j}	-
p_{t-k}	+

Source: own elaboration.

[23] We also estimated an equation replacing import prices with the global price of Brent oil. However, oil prices didn't enter significantly into the equation model.

4.1.1 MODEL ESTIMATION

We estimate the "triangle-model" Phillips curve using the method of Ordinary Least Squares (OLS) for quarterly data from the second quarter of 1949 to the last quarter of 2017. Parameter estimates are presented in table 2 below.

Table 2. "Triangle-model" Phillips Curve Estimates: Quarterly Inflation Rate, CPI excl. Food and Energy

Variable	Coefficient	t-Statistic	p-value
α_0	0.2065	2.0431	0.0420
	(0.1011)		
$\Delta\pi_{t-1}$	0.3883***	6.5269	0.0000
	(0.0595)		
$\Delta\pi_{t-2}$	0.1060*	1.7823	0.0758
	(0.0595)		
$\Delta\pi_{t-3}$	0.1921***	3.7987	0.0002
	(0.0506)		
$\Delta\pi_{t-4}$	-0.4875***	-6.1173	0.0000
	(0.0797)		
U_{t-1}	-0.3363***	-6.1934	0.0000
	(0.0543)		
U_{t-2}	0.3009***	5.6527	0.0000
	(0.0532)		
Δp_t	-0.0248	-1.4763	0.1411
	(0.0168)		
Δp_{t-1}	-0.0104	-0.5126	0.6087
	(0.0202)		
Δp_{t-2}	-0.0296**	-2.1842	0.0298
	(0.0135)		
Δp_{t-3}	0.0747***	5.1623	0.0000
	(0.0145)		
Δp_{t-4}	0.0445***	4.5487	0.0000
	(0.0099)		
Included observations	275		
R-squared	0.5702		
Adjusted R-squared	0.5522		
F-statistic	31.7207		
Prob(F-statistic)	0.0000		

Asymptotic standard errors for the parameter estimates are reported in parentheses.

* Significant at the 10 per cent level.

**Significant at the 5 percent level.

***Significant at the 1 percent level.

Source: estimated parameters are own elaboration.

The estimated sum of the two coefficients on the the unemployment rate is around – 0.035 percentage points, reflecting the expected negative sign. However, the low coefficient on the unemployment level effect suggests less sensitive changes in the core CPI inflation to labor market tensions. The first lag of the unemployment rate indicates that an increase by one percentage point in the unemployment rate in the last quarter results in a decrease by roughly 0.34 percentage points in the core CPI inflation rate and it is statistically significant at the 1% level, while the implied change effect is – 0.30; therefore, for a given level of unemployment, the change effect shows that every percentage point increase in the unemployment rate drops the inflation rate by 0.30 percentage points.

The sum on the four lagged values of inflation is 0.20 per cent, indicating a small but positive explanatory power of the past year changes in the values of the core CPI inflation in explaining changes in its actual value. The four lags of the inflation rate are all statistically significant, and we are unable to reject the hypothesis that the sum of the coefficients equals unity at conventional significance levels, as suggested by Fuhrer (1995). If the sum of the coefficients would have been close to the unity, then shocks to inflation would have had long-lasting effects (Mishkin, 2007) and, in the long-run, the inflation rate would have equalized the expected inflation (as we use past inflation as a proxy for inflation expectations). However, in our case, the core CPI inflation has grown less persistently over the entire sample period, implying that a shock to inflation has only a temporary effect, reflecting an inflation that reverts back to its trend level more rapidly (Mishkin, 2007).

The sum on the coefficients on the import prices indicates a 0.05 percentage points increase in the inflation rate when import prices increase by one per cent. The coefficients on the four lags are overall significant, in particular the third and fourth quarters that are statistically significant at 1 per cent level. Moreover, the inclusion of past year values of import prices in the model is useful because previous import price fluctuations contain expectations on future movements of their respective current values.

Thus, one of the important findings that emerged from the estimation of our Phillips curve is the relatively higher impact of the estimated sum of the coefficients on import prices in explaining changes in the domestic inflation process with respect to the sum of the coefficients on the unemployment rate, implying less sensitive core CPI inflation fluctuations to labor market tensions.

Robustness tests

As a robustness test, we include the contemporaneous value of the unemployment rate in order to assess the effect of its current value on inflation. Moreover, we add two more lags of the unemployment rate in order to analyze its effect on inflation over a longer period of time.

Thus, we estimated the following modified version of the base specification model:

$$\Delta\pi_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \Delta\pi_{t-i} + \rho_t U_t + \sum_{j=1}^{4} \beta_j U_{t-j} + \sum_{k=1}^{4} \gamma_k \Delta p_{t-k} + \epsilon_t$$

where α_0 represents the constant, π_t indicates the annual core CPI inflation, π_{t-i} denotes the lag of annual core CPI inflation, U_t is the contemporaneous value of the unemployment rate, U_{t-j} indicates the lagged value of the civilian unemployment rate, p_t represents the price of imports index and the final term denotes the disturbance term.

Table 19 in the appendix reports the corresponding results. Here, it is only worth noting that we unexpectedly found a positive sign on the coefficients of the contemporaneous value of the unemployment rate, where an increase by one per cent of the unemployment rate today leads to a raise of inflation by 0.02 per cent. This coefficient, however, resulted statistically insignificant.

This finding didn’t affect much the main results of this model as the sum of the coefficients on the four lags of the unemployment rate has the expected negative sign, where an increase by one per cent of the unemployment rate leads to a decrease by 0.04 percentage points of inflation. However, even in this case, those coefficients resulted statistically insignificant overall.

In conclusion, the estimated coefficients on sum of the lagged values of inflation and import prices didn’t change significantly with respect to the base specification model.

After this brief discussion on the estimation of the aforementioned model, we go back to analyze in more details the robustness of our base specification model in table 2.

We can see that for the full sample period the adjusted R^2 denotes that the model can explain more than half of the variation in inflation. The F-statistic also shows a high jointly statistical significance of the set of explanatory variable included in the model in order to explain inflation dynamics. We also use the Newey-West covariance method in the estimation of the model in order to overcome problems of heteroskedasticity in the error terms. This procedure adjusts the standard errors in order to obtain a more accurate sized test statistics (Newey and West, 1994). In addition, when looking at time series analysis, we are interested in whether the sequential points in the residuals of time series affect each other in a dependent way over time. We tested for serial correlation by performing a Breusch–Godfrey serial correlation test. The null hypothesis of this test is that there is no serial correlation of any order among the error terms of the regression model. The corresponding results reported in table 3 below indicates that we fail to reject the null hypothesis of no evidence of serial correlation among the residuals in our base specification model at 1 per cent significance level.

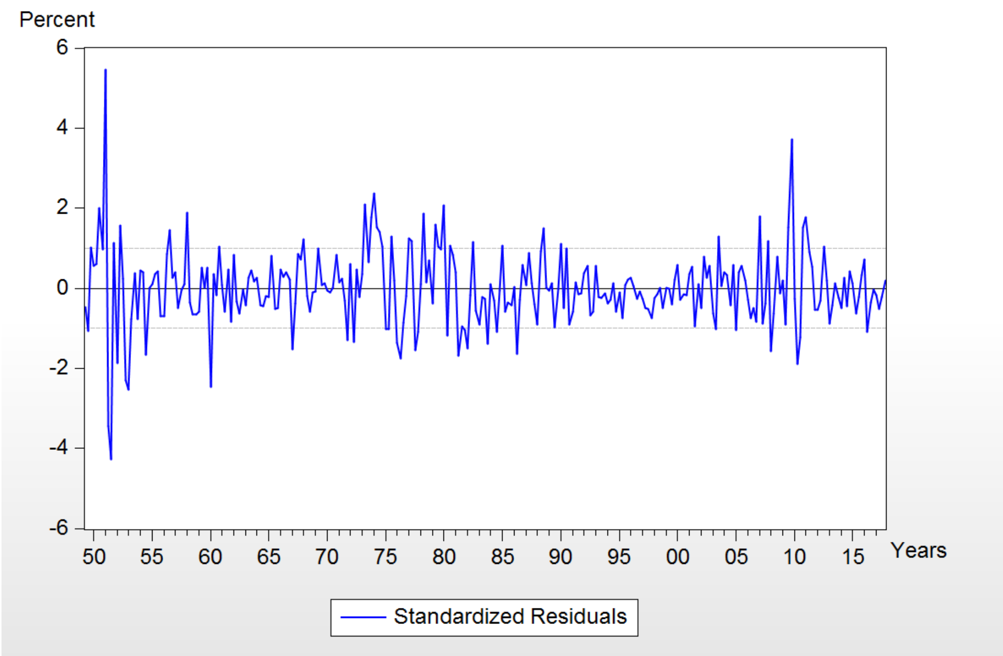
Table 3. Breusch–Godfrey serial correlation test of the estimated base specification model

F-statistic	5.3881	Prob. F(12,251)	0.0000

Source: own elaboration

Moreover, figure 4 below shows the structure of the standardized residuals from our estimated base specification model equation.

Figure 4. Behavior of the residuals from the estimated "Triangle-model" Phillips Curve



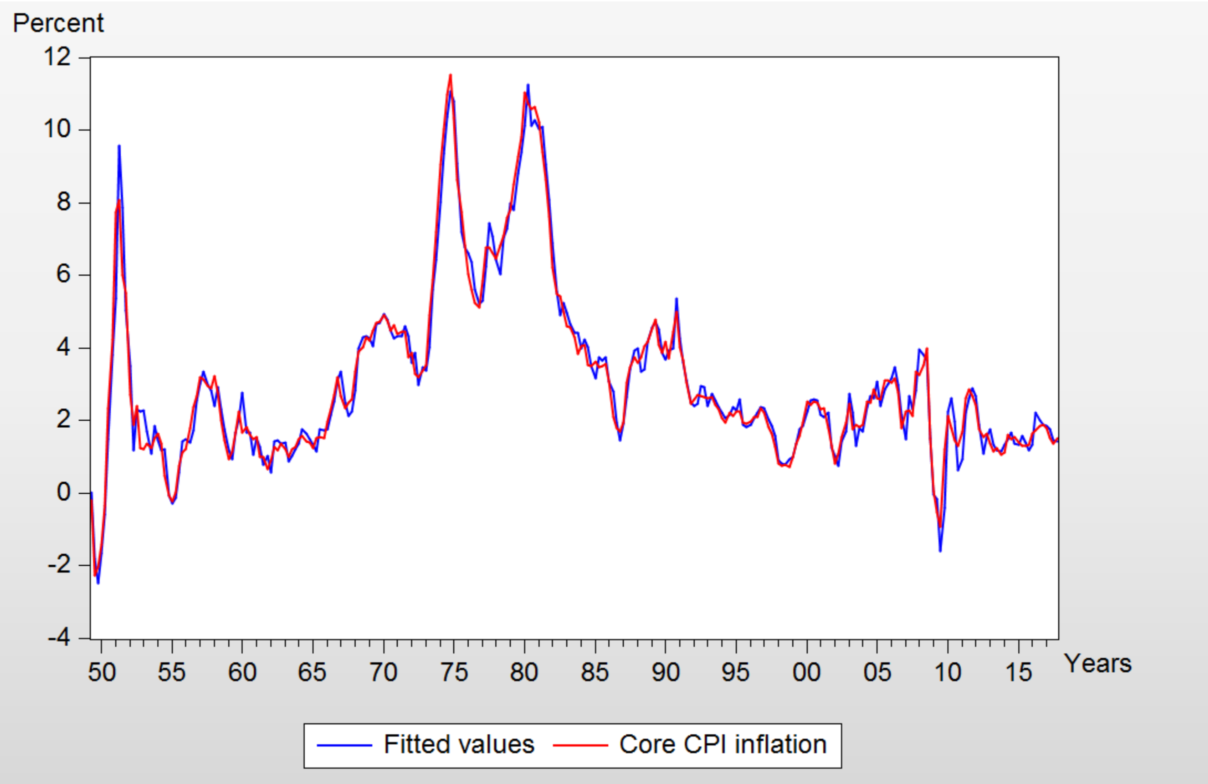
Source: own elaboration.
Note: Standardized residuals path over the entire sample period.

The graph above displays a clear stationary behavior of the residuals of our base specification model regression with the only exception of some major deviations in the 1949-1952 period, the 1970-80 period, and in the 2010s. Therefore, there is no evidence of non-stationarity among the residuals in our estimated base specification model regression.

4.1.2 MODEL STATIC FORECAST OVER THE 1949:II to 2017:IV

Figure 5 below displays a one-period ahead forecast test that highlights the actual data for the core CPI inflation and the fitted values from the estimated equation model. As the figure shows, there is no sign that the Phillips curve wonders off track over the entire sample period.

Figure 5. Actual Core CPI Inflation Rate vs. Fitted Values from Estimated Phillips Curve



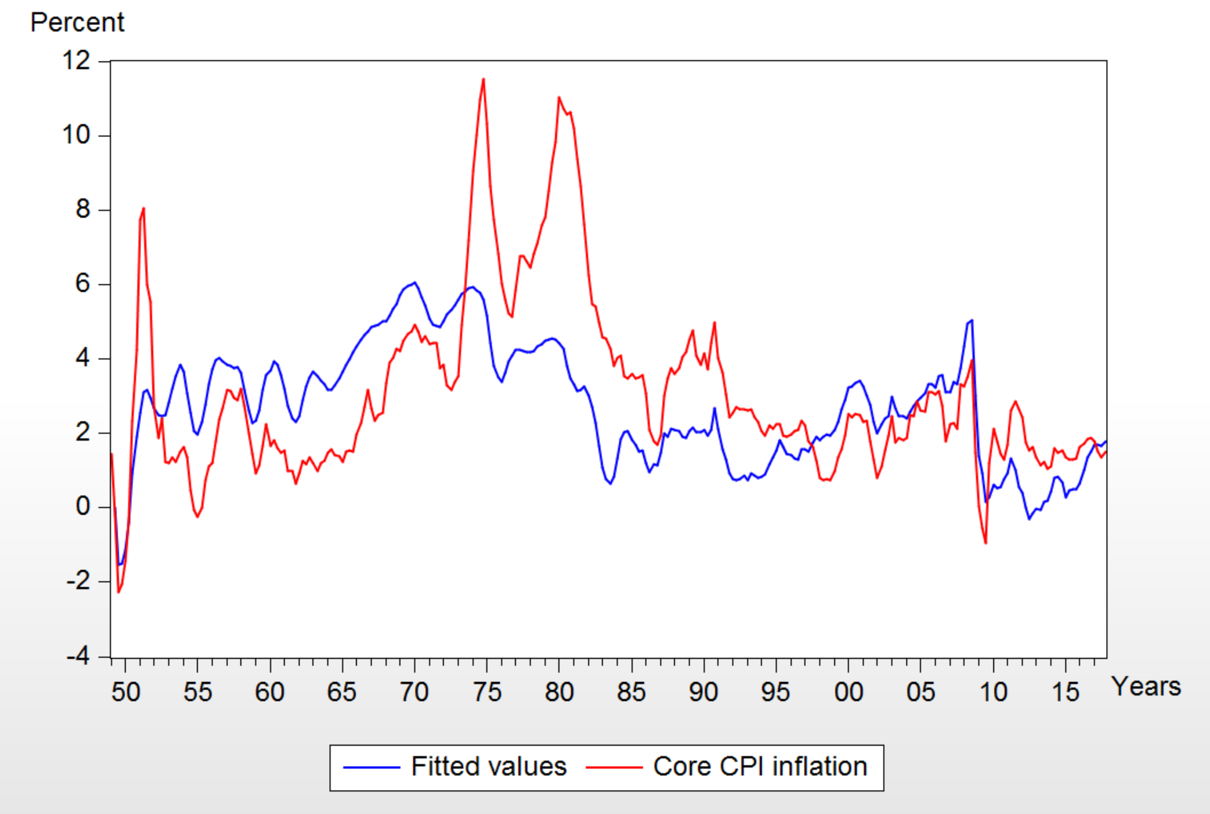
Source: own elaboration

Note: One period head forecast of the Consumer Price Index excluding food and energy, seasonally adjusted, U.S. Bureau of Labor Statistics. The fitted values are the parameters estimated from the base specification model.

4.1.3 DYNAMIC TRACKING PERFORMANCE OVER THE 1949:II to 2017:IV

Figure 6 below, instead, displays the dynamic tracking performance of the Phillips curve over the entire sample period. This is a dynamic simulation performed in order to reveal the multi-period dynamic tracking performance of changes in the inflation pattern. Moreover, it differs from the previous static forecast test because it uses the predicted values for the lagged dependent variable. Thus, by implication, the Phillips curve can significantly wander off track if the model equation is wrongly specified, due to the fact that a large error in predicting inflation can subsequently feed into all the other predictions (Fuhrer, 1995). As we can see from the figure below, the base specification model overestimate inflation for the 1953-1958 and the 1962-1970 period, while it underestimates inflation from the 1975-1995 and the 2011-2014 period. The estimated Phillips curve instead performed really well during the 2000-2010 period, while showing sign of re-stabilization of its path with respect to the actual inflation pattern during the last two years.

Figure 6. Dynamic Simulation of Core CPI Phillips Curve Estimated over 1949:II to 2017:IV

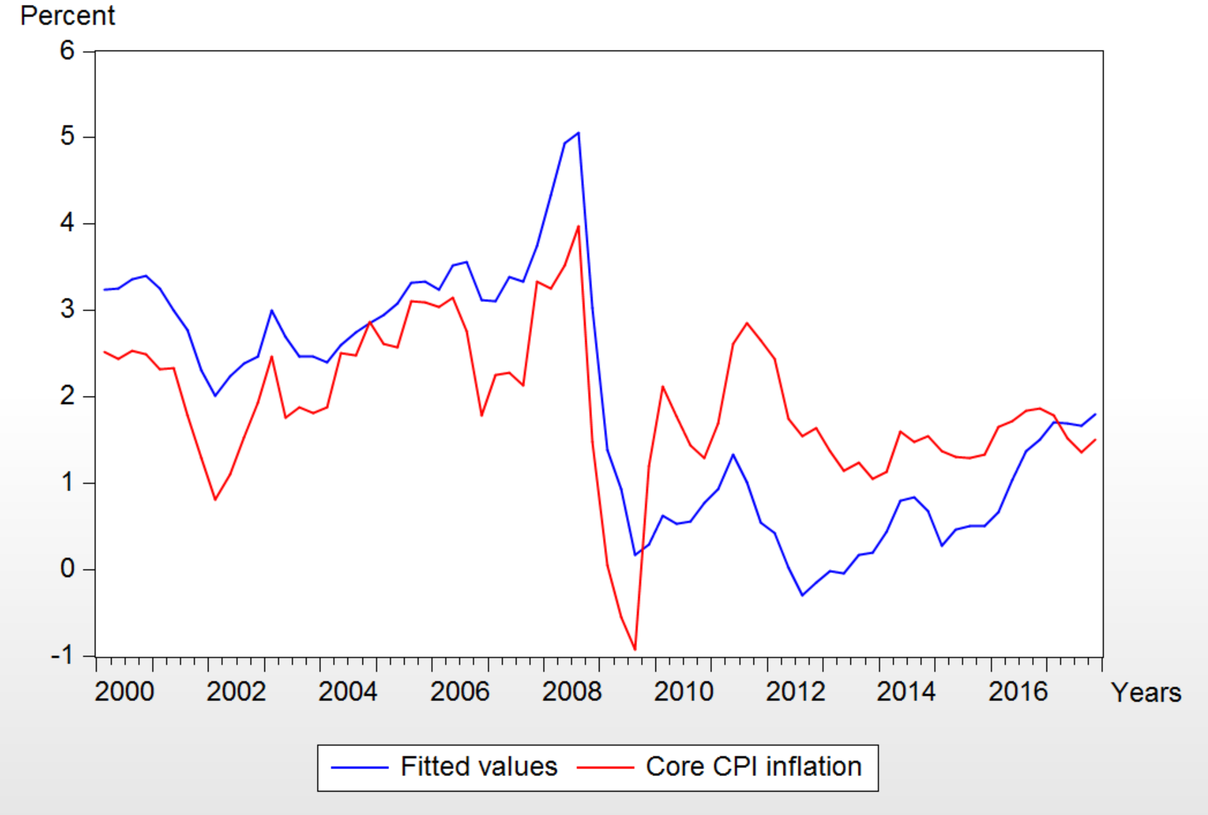


Source: own elaboration.

Note: Dynamic simulation forecast of the Consumer Price Index excluding food and energy, seasonally adjusted, U.S. Bureau of Labor Statistics. The fitted values are the parameters estimated from the base specification model.

Having a look more in details to the behavior of the Phillips curve in the recent period, we provide a more detailed dynamic simulation of the estimated model over the period 2000:I to 2017:IV in figure 7 below. We can note that the estimated Phillips curve slightly overestimates the actual value of the core CPI inflation from 2000 until the 2008 period, while underestimating actual inflation from 2010 to 2016 and overestimating it again during the 2017s. Despite that, the estimated Phillips curve equation capture really well changes in inflation during the period of the financial crisis starting from the 2008s until the 2009s. Overall, we can clearly see that the estimated model predicts quite well actual inflation. However, an estimated 0 per cent level of inflation in 2012 represents the only exception of the overall good dynamic tracking performance. Therefore, we can deduct that the Phillips curve is well and alive in the United States, at least until the end of the last year. Moreover, we can still consider it as a suitable macroeconomic relationship able to capture core CPI inflation dynamics in the U.S. economy.

Figure 7. Dynamic Simulation of Core CPI Phillips Curve over 2000:I to 2017:IV



Source: own elaboration.

Note: Dynamic simulation forecast of the Consumer Price Index excluding food and energy, seasonally adjusted, U.S. Bureau of Labor Statistics. The fitted values are the parameters estimated from the base specification model only for the 2000:I to 2017:IV period.

4.1.4 MODEL STABILITY OVER THE 1959:IV 2007:III PERIOD

We further conduct a Quandt-Andrews breakpoint test in order to examine the stability of our base specification model parameters' coefficients. We choose this test because it provides an agnostic view of possible structural breaks that could have occurred over the sample period. The Quandt-Andrews breakpoint test tests for parameters instability and structural changes with unknown change points in the sample for our base specification model equation. The background idea is that a single Chow breakpoint test[24] is performed at each adjusted observation between two dates. Then, the test statistics from those Chow tests are gathered in one test statistic for a further test against the null hypothesis of no breakpoints between the two chosen dates. Here, we provide the Likelihood Ratio F-statistic test retained by every Chow breakpoint test performed. The Likelihood Ratio F-statistic is based on the comparison of the restricted and unrestricted sums of squared residuals.

In order to test for an unknown structural break point amongst all the original regressors we run the Quandt-Andrews test with 15% trimming data[25]. This test gives the following results:

Table 4. Quandt-Andrews unknown breakpoint test of the estimated traditional Phillips curve

Statistic	Value	p-value
Maximum LR F-statistic (1960Q2)	5.3841	0.0000

Null Hypothesis: No breakpoints within 15% trimmed data
Test Sample: 1959:IV 2007:III
Number of breaks compared: 192

Source: own elaboration

Note: probability calculated using Hansen's (1997) method.

Table 4 above shows that there is at least one structural break in our base specification model, and that the most likely date refers to the second quarter of the 1960[26]. However, it is possible

[24] It tests the null hypothesis of constant parameters against the alternative hypothesis of a one-time shift in the parameters at some specified date.
[25] We choose the standard level of symmetric observation trimming for the test.
[26] Most likely due to the recession of 1960-1961 period.

that further structural breaks could result in other periods, also because the test excludes the first and last ten years of our data sample. Therefore, in order to test directly the stability of the expectations component of the Phillips curve, we perform a Chow test in order to test the null hypothesis of constant parameters against the alternative hypothesis of a one-time shift in the parameters at some specified date. By implication, performing this test is useful in order to investigate in whether there have been important shifts in the coefficients of our "triangle-model" parameters of the Phillips curve when important changes in monetary policy decisions have been deployed in the economy[27]. Here we focus on the last quarter of 2008, when the Federal Reserve Bank started unconventional large-scale purchases of Treasuries and agency mortgage-backed securities (MBS) from banks and financial institutions through the so-called quantitative easing program (QE), that ultimately resulted as an unconventional monetary policy measure pursued in order to raise the inflation rate in the U.S. economy in that period. In fact, an increase in securities purchases by the FED aims to increase liquidity in the markets which consequently should leads to easing lending conditions and lower interest rates, which in turn should lead to higher inflation (Fawley & Neely, 2013).

Hence, formally, we conducted the test to see if we can fail to reject the null hypothesis that the estimated coefficients that refers to our base specification model didn't shift significantly due to monetary policy change.

Table 5 provides the results from the Chow test of the coefficients stability for the breakpoint centered around the last quarter of 2008.

Table 5. Chow Breakpoint Tests centered around the last quarter of 2008 for the estimated traditional Phillips curve

Breakpoints	F-statistic	Prob. F(12,251)
2008 Q3	2.1792	0.0132
2008 Q4	2.2410	0.0106
2009 Q1	2.2575	0.0100
2009 Q2	2.2486	0.0103

Null Hypothesis: No breaks at specified breakpoints

Source: own elaboration.

As shown by the reported values of the test statistics in Table 5, we fail to reject the null hypothesis of parameter stability for the pre and post 2008 period at the 5 per cent significance

[27] This turns out to be an assessment of the famous Lucas' critique.

levels. Therefore, the results of our dynamic simulation suggest that a shift in the estimated coefficients of the Phillips curve didn't occur in relation to change in monetary policy decisions, implying a stable Phillips curve in the U.S. over a long period of time, providing evidence against the Lucas' critique.

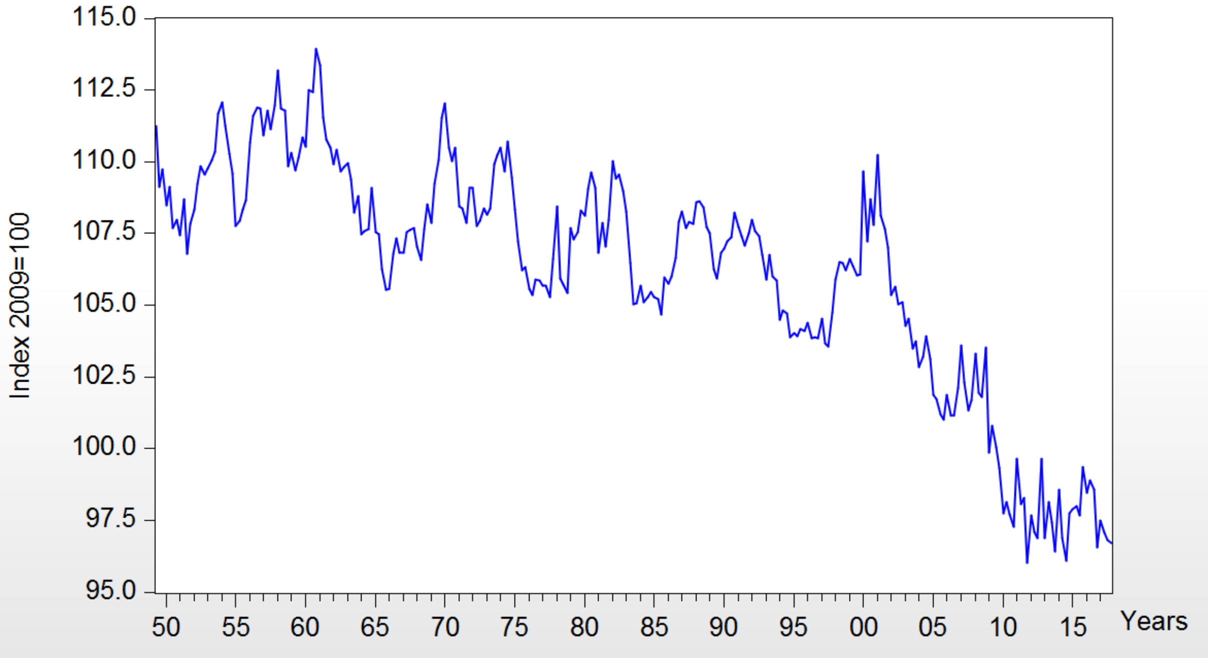
We perform a further Chow tests in order to test the stability of our Phillips curve in the occurrence of another major monetary policy change. We decide to focus on October 1979, when the Fed changed its operating procedures, thus beginning its disinflation program (Volcker disinflation program). We test the null hypothesis of constant parameters against the alternative hypothesis of a one-time shift in the parameters around the 1979 period in the US. The corresponding results reported in table 22 in the appendix indicates that we fail to reject the null hypothesis of parameter stability for the pre and post 1979 period at the 1 per cent significance levels, thus confirming again the stability of our estimated coefficients in the occurrence of monetary policy changes.

However, even if overall our base specification Phillips curve model results stable, its dynamic tracking performance in the last five years didn't' perform really well in predicting an actual core CPI inflation that remained relatively low during the same period of time. For this reasons, we decide to replace the unemployment rate with a proxy of firms' real marginal costs of labor[28] denoted by the labor share of income in the nonfarm business sector in the U.S. economy[29] in order to explain the recent behavior of the consumer price levels. We make this choice due to the fact that the workers share in the U.S. economy's output have not only failed to reflect an acceleration but have also showed an overall downward trend in the U.S. economy during the last seventeen years, as we can see from figure 8 below. Hence, these observed patterns can support the idea that labor share of income might be a key factor in understanding the recent relatively low consumer prices dynamics (Lown and Rich, 1997). Furthermore, we assume that the inclusion of a different measure of labor market slack in the model replacing unemployment rate can help us in a better understanding of the link between U.S. economy exposure to the global trade and changes in the inflation process, due to the fact that in the previous model the only variable capturing these dynamics is the average percentage change in import prices. In particular, labor share of income captures important dynamics in the labor market that differs

[28] Nominal marginal cost divided by the price level.
[29] As also suggested by Galì and Gertler (1999).

from the labor market tensions that derive from the rate of the unemployment, as we will see in the next section.

Figure 8. Nonfarm Business Sector: Labor Share in U.S.



Source: own elaboration.

Note: data retrieved from U.S. Bureau of Labor Statistics.

4.2 MODIFYING THE TRADITIONAL MODEL

We slightly change our base specification model replacing the unemployment rate by firms' real marginal costs as a measure of economic slack proxied by the labor share income of the nonfarm business sector in the United States[30]. The modified base specification model is therefore given by:

$$\Delta\pi_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \Delta\pi_{t-i} + \sum_{j=1}^{2} \beta_j W_{t-j} + \sum_{k=1}^{4} \gamma_k \Delta p_{t-k} + \epsilon_t$$

where α_0 represents the constant, π_t indicates the annual core CPI inflation, π_{t-i} denotes the lag of annual core CPI inflation, W_{t-j} indicates the lagged value of the quarter labor share income of the nonfarm business sector index, p_t represents the price of imports index of all the commodities in the U.S. and the final term denotes the disturbance term.

As for the base specification model, we conduct an Augmented Dickey-Fuller test statistic before the estimation of the aforementioned model in order to test whether the time series that refers to our endogenous variables follow a unit root process or not[31]. The relative findings suggest that every variable[32] results following a stationary process after first differencing(Δ), thus implicitly following an ARMA process.

The labor share[33] income index represents a valid indicator of the compensation that workers receive as a percentage of the economic output. Moreover, it is useful in explaining the extent of the wage gap between labor productivity growth and real hourly compensation growth, where a decline in the labor share increases the gap between these two measures and vice versa, thus representing a measure of economic slack (Giandrea et al. 2017). The widely aforementioned increased international competitiveness facing the U.S. labor market that reduces impact of labor market tensions on inflation translates automatically into a decline in the overall labor costs that, in our model, represent the measure able to capture shocks in the labor market. Therefore, a slowdown in the labor share may reflect a change in the behavior of the labor

[30] This measure covers 75% of the U.S. economy measured in terms of economic output (BEA).
[31] The correspondent ADF tests are displayed in the appendix (tables 14-15-16-17-18).
[32] Excluded the labor share income and the constant term, where the former is stationary in level at 1 per cent significance level.
[33] Calculated by dividing the compensation earned during a certain period by the economic output produced over the same period (BEA).

market in the long-term, where job insecurity can lower the ability of workers to obtain higher wage rates, consequently modifying the link between compensation and change in the price levels (Lown and Rich, 1997). Moreover, the inclusion of import prices acts as control variable capturing shocks on the supply side, where a decline in the price of imported goods due to high degree of openness contributes to curb inflationary pressure in the U.S. economy (Lown and Rich, 1997).

Consequently, for the aforementioned reasons, we expect a better performance of our modified Phillips curve in the recent period with respect to our previous model due to the inclusion of a measure of economic slack that can capture important shifts in the inflation process emanating from the labor market. Therefore, we expect the dynamic tracking performance of the Phillips curve over the last decade to be restored by the inclusion of the effects of labor share income in our model as a measure that is able to capture demand shocks.

4.2.1 MODEL ESTIMATION

We estimate the Phillips curve using the method of Ordinary Least Squares (OLS) for quarterly data from the second quarter of 1949 to the last quarter of 2017. Parameter estimates are presented in table 6 below.

Table 6. Modified Phillips Curve Estimates: Quarterly Inflation Rate, CPI excl. Food and Energy

Variable	Coefficient	t-Statistic	p-value
α_0	0.0059	0.2277	0.8200
	(0.0261)		
$\Delta\pi_{t-1}$	0.4363***	5.8938	0.0000
	(0.0740)		
$\Delta\pi_{t-2}$	0.1238*	1.9087	0.0574
	(0.0649)		
$\Delta\pi_{t-3}$	0.1981***	4.0468	0.0001
	(0.0489)		
$\Delta\pi_{t-4}$	-0.5028***	-6.4823	0.0000
	(0.0776)		
W_{t-1}	0.0466*	1.7061	0.0892
	(0.0273)		
W_{t-2}	0.0577***	2.6992	0.0074
	(0.0214)		
Δp_t	-0.0211	-1.1328	0.2583
	(0.0186)		
Δp_{t-1}	-0.0116	-0.5093	0.6110
	(0.0229)		
Δp_{t-2}	-0.0312*	-1.8142	0.0708
	(0.0172)		
Δp_{t-3}	0.0762***	4.3005	0.0000
	(0.0177)		
Δp_{t-4}	0.0418***	3.8791	0.0001
	(0.0108)		
Included observation	275		
R-squared	0.5414		
Adjusted R-squared	0.5222		
F-statistic	28.2229		
Prob(F-statistic)	0.0000		

Asymptotic standard errors for the parameter estimates are reported in parentheses.

* Significant at the 10 per cent level.

**Significant at the 5 percent level.

***Significant at the 1 percent level.

Source: estimated parameters are own elaboration.

As we can see, both past values of the percentage change in the labor share income in the last two quarters enter overall significantly into the equation model. Moreover, the sum of the coefficients on the two lagged values of labor share income is positive, thus in line with economic theory that generally predicts a raise in output prices when labor firms' labor costs increase. The mechanism that raises consumer prices works through the main channel of higher firms' productivity and consequently higher workers' wages, where tightening labor markets conditions permit workers to bargain for higher wage rates which consequently translates in a raise of output prices (Seydl and Malcolm Spittler, 2016). Therefore, our attention has been focused on the non-accelerating path of the labor share income index because it could have represented the warning alarm of an impending pick-up in inflation during the recent period.

An overall increase in the two past quarters values of the labor share income by a percentage point increases inflation by 0.10 per cent, thus representing a relatively more powerful driving force of inflation with respect to the unemployment rate. The sum on the coefficients of the past year values of import prices and inflation remain unchanged with respect to the previous model. Thus, like the traditional model, the estimated version of the modified model doesn't provide a sum of the coefficients on lagged inflation that equal unity, rejecting the idea that the inflation rate is equal to expected inflation in the long-term. Moreover, it implies an inflation that still has a low persistency over the entire sample period, but that maintain the role of main determinant of actual change in inflation in our model, confirming anyway the idea of the presence of a certain degree of price inertia in the U.S. economy.

Robustness tests

We also slightly changed the modified base specification model by including the contemporaneous value of labor share income in order to verify the effect of its current value on inflation, and by adding two more lags of the labor share income in order to analyze its effect on inflation over a longer period of time. The model is the following:

$$\Delta\pi_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \Delta\pi_{t-i} + \delta_t W_t + \sum_{j=1}^{4} \beta_j W_{t-j} + \sum_{k=1}^{4} \gamma_k \Delta p_{t-k} + \epsilon_t$$

where α_0 represents the constant, π_t indicates the annual core CPI inflation, π_{t-i} denotes the lag of annual core CPI inflation, W_t represents the current value of labor share income of the nonfarm business sector index, W_{t-j} indicates the past quarter value of the labor share of income, p_t represents the price of imports index of all the commodities in the U.S. and the final term denotes the disturbance term.

Table 20 in the appendix reports the corresponding results. Here, it is only worth noting that we found the expected positive sign on the coefficient of the contemporaneous value of the labor share income, where an increase by one per cent of its value leads to a raise of inflation by roughly 0.02 per cent. This results is obviously negligible and even statistically insignificant. In addition, the sum of the coefficients on the four lags of the labor share income has still positive sign, where an increase by one per cent of the labor share income leads to a raise by 0.11 percentage points in inflation. However, also in this case, the sum of the coefficients on the labor share income resulted to be statistically insignificant overall. In conclusion, the coefficients on the estimated parameters of the lagged values of inflation and import prices didn't change significantly with respect to the modified base specification model.

By analyzing more in detail the robustness of our modified base specification model, we can see from table 6 that for the full sample period the main test statistics reflect almost the same values as in the precedent traditional model. The adjusted R^2 denotes that the model can explain more than half of the variation in inflation. The F-statistic also shows a high jointly statistical significance of the set of explanatory variables included in the model in order to explain the changes in the domestic inflation process.

We also use the Newey-West covariance method in the estimation of the model in order to overcome problems of heteroskedasticity in the error terms, adjusting the standard errors in order to obtain better t-statistics as we did for the base specification model.

In addition, the results from the Breusch–Godfrey test reported in table 7 below indicates that we fail to reject the null hypothesis of no evidence of serial correlation among the residuals in our modified base specification model at 1 per cent significance level.

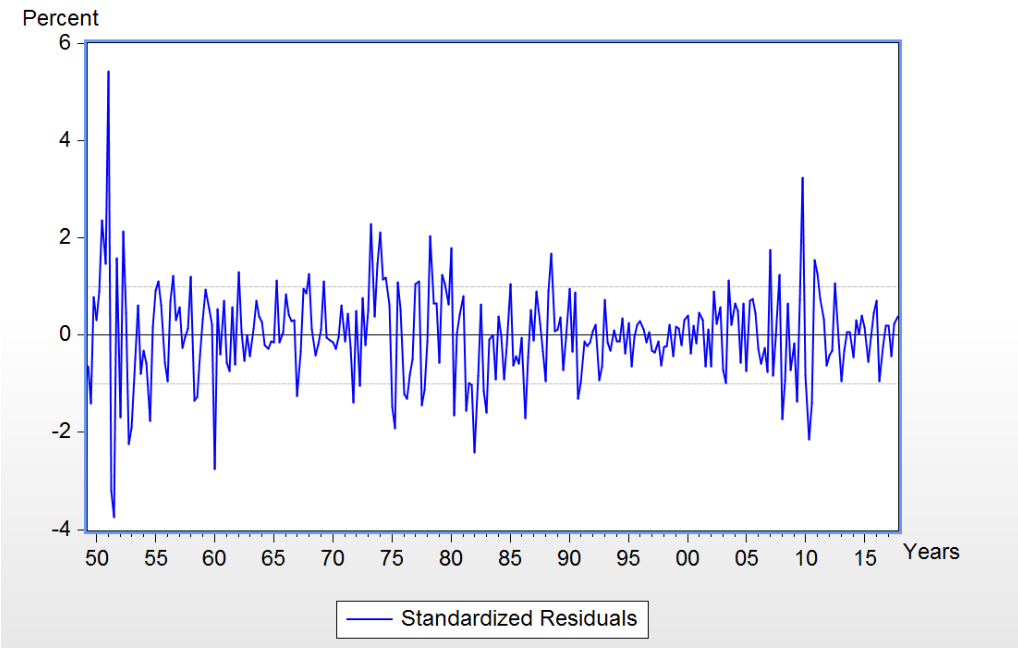
Table 7. Breusch–Godfrey serial correlation test of the estimated modified base specification model

F-statistic	6.5489	Prob. F(12,251)	0.0000

Source: own elaboration.

Figure 9 below shows the structure of the standardized residuals from our estimated modified base specification model equation.

Figure 9. Behavior of the residuals from the estimated modified Phillips Curve



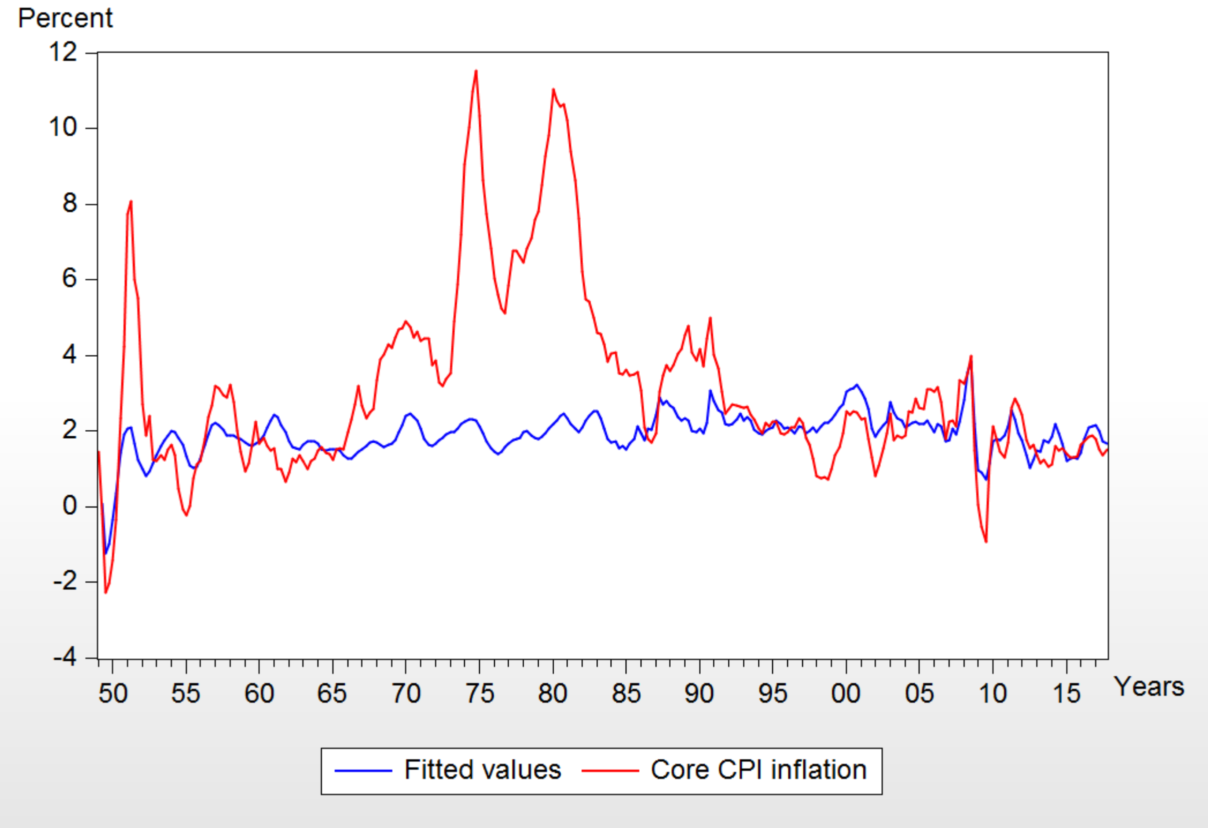
Source: own elaboration
Note: Standardized residuals path over the entire sample period.

The graph above displays an overall stationary behavior of the residuals of our modified base specification model regression with the only exception of some major deviations in the 1949-1952 period, 1970-85, and in the 2010s. Therefore, there is no evidence of non-stationarity among the residuals in our estimated modified base specification model regression.

4.2.2 DYNAMIC TRACKING PERFORMANCE OVER THE 1949:II to 2017:IV

Figure 10 below displays the stable path of our estimated modified Phillips curve equation with the inclusion of labor share income as a measure able to capture firms' real marginal costs. Overall, we can clearly see that the new model explain really well the core CPI inflation dynamics with the only exception of the 1970-1985 period due to the oil price shocks. Therefore, the inclusion of labor share income in the Phillips curve equation as an alternative measure of economic slack with respect to the unemployment rate shows an overall better performance in capturing the changes in the domestic inflation process compared to the previous model.

Figure 10. Dynamic Simulation of modified Core CPI Phillips Curve Estimated over 1949:II to 2017:IV

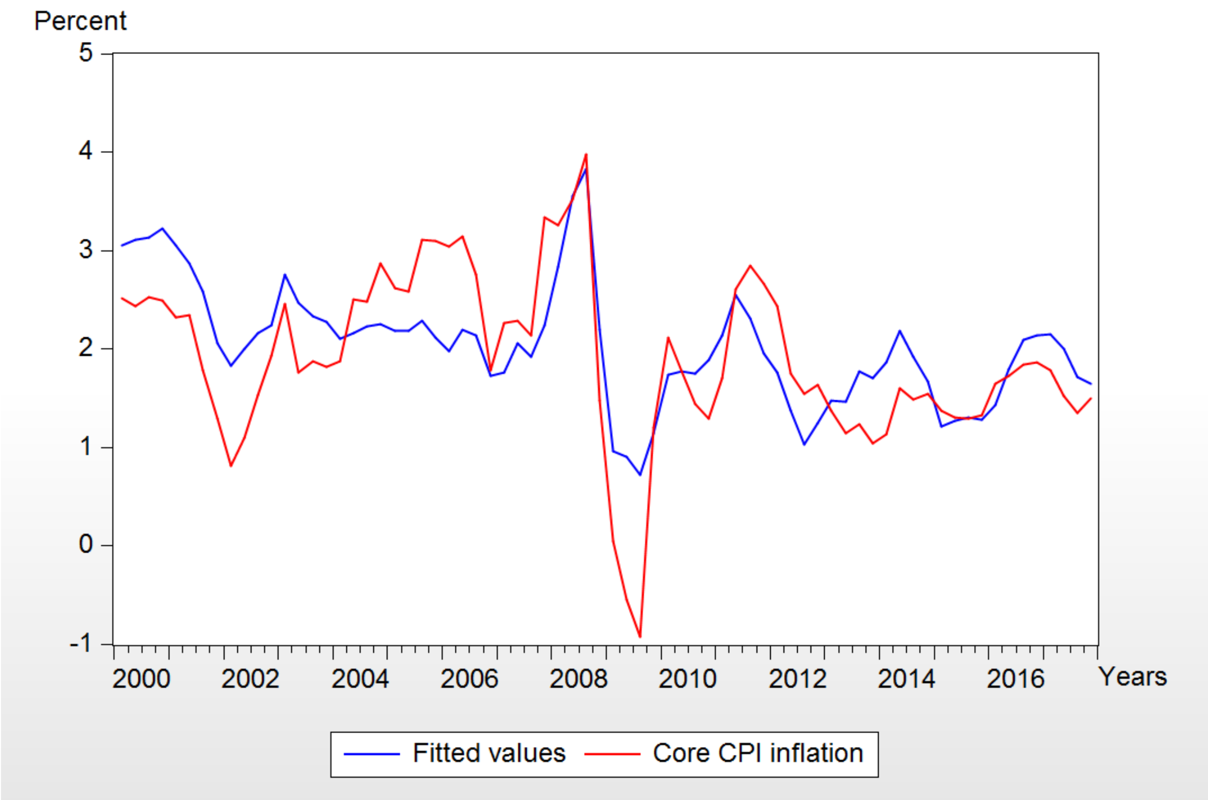


Source: own elaboration.

Note: Dynamic simulation forecast of the Consumer Price Index excluding food and energy, seasonally adjusted, U.S. Bureau of Labor Statistics. The fitted values are the parameters estimated from the base specification model.

In order to further confirm our aforementioned suggestion regarding the appropriateness of the inclusion of labor share income as a measure of economic slack in order to better capture changes in the core CPI inflation, replacing the unemployment rate, we provide a closer look of the relative dynamic tracking performance of the modified estimated Phillips curve over the 2000-2017 period. Figure 11 shows clearly an overall really good performance of our modified model with a Phillips curve that doesn't wonder off track for the entire subsample period. Hence, we can conclude also in this case that the Phillips curve is well and alive in the United States in the current period.

Figure 11. Dynamic Simulation of modified Core CPI Phillips Curve Estimated over 2000:I to 2017:IV



Source: own elaboration.

Note: Dynamic simulation forecast of the Consumer Price Index excluding food and energy, seasonally adjusted, U.S. Bureau of Labor Statistics. The fitted values are the parameters estimated from the base specification model.

4.2.3 MODEL STABILITY OVER THE 1959:IV 2007:III PERIOD

We perform a Quandt-Andrews unknown breakpoint test in the same fashion as we did for the previous model in order to test the null hypothesis of no evidence of structural breaks over the sample period. The results in table 8 below indicates that the most likely probability of occurrence of a structural break in the chosen sample period is in the second quarter of 1960. Hence, the test provides the same result of the previous stability test for the base specification model.

Table 8. Quandt-Andrews unknown breakpoint test for the estimated modified Phillips curve

Statistic	Value	p-value
Maximum LR F-statistic (1960Q2)	5.4776	0.0000

Null Hypothesis: No breakpoints within 15% trimmed data
Test Sample: 1959Q4 2007Q3
Number of breaks compared: 192

Source: own elaboration.

Note: probability calculated using Hansen's (1997) method.

However, the possibility of occurrence of potential structural breaks in the subsequent periods is ruled out by the choice that we have made in trimming the 15 per cent of the data sample as standard level practice for the test. Hence, we perform a Chow breakpoint test in order to test the possible occurrence of shifts in the coefficients of the variables in our model due to changes in monetary policy decisions (resulting again in an assessment of the Lucas' critique). Here, we also center the test around the same specific dates chosen for the previous model that refer to the beginning of the Quantitative Easing program pursued by the FED in the last quarter of 2008. The results are showed in table 9 below.

Table 9. Chow Breakpoint Tests centered around last quarter of 2008 for the estimated modified traditional Phillips curve

Breakpoints	F-statistic	Prob. F(12,251)
2008 Q3	1.8541	0.0406
2008 Q4	1.8262	0.0445
2009 Q1	1.8843	0.0367
2009 Q2	1.8588	0.0399

Null Hypothesis: No breaks at specified breakpoints

Source: own elaboration.

As shown by the reported value of the Chow breakpoints test statistics in Table 9, we fail to reject the null hypothesis of parameter stability for the periods of time centered around the last quarter of 2008 at the 5 per cent significance level. Therefore, also in this case, we can further confirm evidence of the stability of our estimated parameters coefficients against the Lucas' critique.

In addition, we also conduct a further Chow test in order to test the stability of our Phillips curve in the occurrence of another major monetary policy change as we did previously. Also in this case, we decide to focus on the Volcker disinflation program started during the last quarter of 1979. We test the null hypothesis of constant parameters against the alternative hypothesis of a one-time shift in the parameters around the 1979 period in the US. The corresponding results reported in table 23 in the appendix indicates again that we fail to reject the null hypothesis of parameter stability for the pre and post 1979 period at the 1 per cent significance levels, confirming again the stability of our estimated coefficients in the occurrence of monetary policy changes.

However, even though both the estimated models provided us evidence against the Friedman-Phelps-Lucas view regarding the role of expectations in the context of the Phillips curve, we are still interested in the role that inflation expectations play in the Phillips curve framework due to the fact that both our models reflected a lower degree of price persistency and a core CPI inflation that doesn't equalize expected inflation in the long-run. Therefore, we want to analyze the role of forward-looking components of inflation by explicitly incorporating a measure of future inflation expectations in our traditional Phillips curve model.

4.3 A HYBRID FORM OF THE PHILLIPS CURVE

We modify our base specification model[34] by explicitly including a forward-looking component of inflation. Therefore, we want to estimate a hybrid form of the Phillips curve and assess its relative appropriateness in capturing actual changes in consumer price levels. The reason lies also in the fact that our previous model doesn't provide evidence of an inflation that, in the long-run, equalizes expected inflation. Therefore, an explicitly inclusion of a variable that can capture the way how private agents form their expectations about future inflation can help us in obtaining important insights on the influence of expectations formation in shaping the current changes in inflation (Fuhrer and Olivei, 2010). By implication, we want to assess both the roles that backward- and forward-looking components play in a hybrid Phillips curve model in order to explain the inflation process. Therefore, our new specification model is given by:

$$\Delta\pi_t = \alpha_0 + \sum_{i=1}^{6} \alpha_i \Delta\pi_{t-i} + \sum_{j=1}^{2} \beta_j U_{t-j} + \sum_{k=1}^{4} \gamma_k \Delta p_{t-k} + \delta\Delta\pi_{t+1}^{e} + \epsilon_t$$

where α_0 represents the constant term, π_t indicates the annual core CPI inflation, π_{t-i} denotes the lag of annual core CPI inflation, U_{t-j} indicates the lagged value of the civilian unemployment rate, p_t represents the average percentage change in the price of imports, π_{t+1}^{e} represents the expected inflation during the next year and the final term denotes the disturbance term.

Before estimating this new specification model, we conduct an Augmented Dickey-Fuller test statistic in order to test whether the time series that refers to our endogenous variables follow a unit root process or not[35]. The correspondent findings indicate that every variable[36] results following a stationary process after first differencing(Δ), therefore implicitly following an ARMA process.

[34] Here we use unemployment rate as a measure of economic slack because labor share income doesn't enter significantly into the estimated model.
[35] The correspondent ADF tests are displayed in the appendix (tables 14-15-16-17-18).
[36] Excluded the unemployment rate and the constant term, where the former is stationary in level at 1 per cent significance level.

In this new view of the Phillips curve, expectations about inflation are measured by the percentage that consumers expect the price of goods and services to change during the next 12 months[37]. This hybrid Phillips curve resembles the micro-founded New Keynesian Phillips curve that has characterized current inflation as a function of firms' expectations about future price levels (Coibion et al. 2017), with the exception of the inclusion of backward-looking components of inflation. Following Galì and Gertler (1999), we also assume a framework where price setters have backward and forward-looking price adjustment behaviors when set-up economic decisions and workers adjust their expectation with respect to the previous and future course of the economy.

However, recalling that we measure expected inflation by the periodic survey of the Michigan Survey Research Center, we highlight limited reliance on survey data as proxies for expected inflation mainly due to the fact that respondents have no such great incentives to provide proper thoughtful answers. Therefore, even though the expected inflation for next year calculated from the Michigan Survey Research Center has been proven to be an accurate indicator of the future course of the national economy, we still consider the survey a poor proxy for actual inflation expectations, that can translate in an introduction of a relative degree of noise in the estimation model (Roberts, 1995).

4.3.1 MODEL ESTIMATION

We estimate the hybrid Phillips curve using the method of Ordinary Least Squares (OLS) for quarterly data from the second quarter of 1978 to the third quarter of 2017. Parameter estimates are presented in table 10 below.

[37] We were not able to find an accurate measure for firms' expectation about inflation that enter significantly into the equation model.

Table 10. Hybrid Phillips Curve Estimates: Quarterly Inflation Rate, CPI excl. Food and Energy

Variable	Coefficient	t-Statistic	p-value
α_0	0.0136	0.1469	0.8834
	(0.0925)		
$\Delta\pi_{t-1}$	0.3457***	4.4300	0.0000
	(0.0780)		
$\Delta\pi_{t-2}$	0.1125	1.1453	0.2540
	(0.0982)		
$\Delta\pi_{t-3}$	0.1009	1.6227	0.1069
	(0.0622)		
$\Delta\pi_{t-4}$	-0.4774***	-4.5140	0.0000
	(0.1058)		
$\Delta\pi_{t-5}$	0.1682*	1.9451	0.0537
	(0.0865)		
$\Delta\pi_{t-6}$	0.1503***	3.0786	0.0025
	(0.0488)		
U_{t-1}	-0.2153**	-2.3444	0.0204
	(0.0918)		
U_{t-2}	0.2106**	2.3540	0.0199
	(0.0895)		
Δp_t	-0.0210*	-1.7873	0.0760
	(0.0118)		
Δp_{t-1}	-0.0018	-0.1140	0.9094
	(0.0160)		
Δp_{t-2}	-0.0261**	-2.0274	0.0445
	(0.0129)		
Δp_{t-3}	0.0443***	3.2083	0.0016
	(0.0138)		
Δp_{t-4}	0.0282**	2.0448	0.0427
	(0.0138)		
$\Delta\pi^e_{t+1}$	0.3015***	4.0715	0.0001
	(0.0741)		
Included observations	158 after adjustments		
R-squared	0.6497		
Adjusted R-squared	0.6154		
F-statistic	18.9406		
Prob(F-statistic)	0.0000		

Asymptotic standard errors for the parameter estimates are reported in parentheses.

* Significant at the 10 per cent level.

**Significant at the 5 percent level.

***Significant at the 1 percent level.

Source: estimated parameters are own elaboration.

We can see that the coefficient on expected inflation enter significantly into our new specification model. A one percentage point increase in the expected inflation translates into an increase by 0.30 percentage points in the actual core CPI inflation. In this case, we include more lags on the level of past changes in inflation because the sum of the first four quarters doesn't have the expected positive sign into the equation model. The sum on the six lagged values of past changes in the core CPI inflation rate is 0.40 percentage points. Therefore, in this case, the core CPI inflation has grown more persistently over the entire sample period. The sum of the two lags of the unemployment rate coefficients is -0.005 percentage points. The coefficient on the first lag of the unemployment rate is -0.215 per cent while the implied change effect is -0.21. Therefore, we can deduce that the inclusion of the expected inflation component has "absorbed" a high portion of the unemployment level effect, resulting in an even less sensitive U.S. inflation to labor market tensions with respect to our baseline specification model. Moreover, as our findings highlight, an almost non responsive core CPI inflation to labor market tensions imply a very weak bargaining position of workers that manifest itself as a flat Phillips curve slope.

The overall effect of the import prices has also decreased. The sum on the coefficients on the prices of the imported goods is 0.02 percentage points. Moreover, as a further confirmation of the findings relative to the base specification model, import prices represent one of the main determinants of the changes in the inflation process, confirming the idea that "the prices of goods consumed in the U.S. economy today are most likely determined by the prices of imported goods" (Joe Seydl & Malcolm Spittler, 2016, p.402).

We can conclude that the changes in the core CPI inflation in our hybrid Phillips curve model are mainly driven by its own past values and by private agents' expectations about its future course, with backward-looking components that have a relatively higher explanatory power with respect to the forward-looking components. In this framework, the resulted higher inflation persistence can be attributed to the stabilization of the Federal Reserve's inflation target in the long-run, as suggested by Ball and Mazumder (2015). Furthermore, part of the core CPI inflation in our hybrid model is also characterized by private agents' expectations about future inflation that are also driven by the inflation target goal of the Federal Reserve in the long-run. Therefore, we can deduce that there is an interconnection between a certain degree of inflation persistency in the economy, firms' and workers' forward-looking expectations about inflation and the inflation-targeting central bank policy (Leitemo, 2008), where a combination of history-dependent and forward-looking inflation components in a

Phillips curve equation model result in a larger explanatory power in order to capture changes in inflation dynamics during a long time period in the United States.

Robustness tests

It is worth highlighting that, also in this case, we estimate a modified version of the hybrid Phillips curve model by including the contemporaneous value of the unemployment rate in order to verify the effect of its current value on inflation, and by adding two more lags of the unemployment rate in order to analyze its effect on inflation over a longer period of time. In addition, we also removed two lags of the core CPI inflation in order to equalize the length of the lags for all the parameters in the equation. The modified hybrid model is given by:

$$\Delta\pi_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \Delta\pi_{t-i} + \theta_t U_t + \sum_{j=1}^{4} \beta_j U_{t-j} + \sum_{k=1}^{4} \gamma_k \Delta p_{t-k} + \delta\Delta\pi_{t+1}^{e} + \epsilon_t$$

where α_0 represents the constant term, π_t indicates the annual core CPI inflation, π_{t-i} denotes the lag of annual core CPI inflation, U_t represents the current value of the unemployment rate, U_{t-j} indicates the lagged value of the unemployment rate, p_t represents the average percentage change in the price of imports, π_{t+1}^{e} represents the expected inflation during the next year and the final term denotes the disturbance term.

Table 21 in the appendix reports the corresponding results. Here, it is only worth noting that we found, as expected, a negative sign on the coefficient of the contemporaneous value of the unemployment rate, where an increase by one per cent of the unemployment rate leads to a fall in inflation by 0.09 per cent. This coefficient, however, results statistically insignificant. Moreover, the sum of the coefficients on the four lags of the unemployment rate has the expected negative sign, where an increase by one per cent of the unemployment rate leads to a decrease by 0.02 percentage points of inflation. Finally, the coefficients on the estimated parameters of the lagged values of inflation, the sum on the coefficients of the import prices and the coefficient on expected inflation remained almost unchanged with respect to the original hybrid model.

We go back to analyze the main test statistics of our hybrid model reported in table 11. We highlight an adjusted R^2 values that reflects a model that can explain a higher portion of the variation in inflation with respect to the two previous models adopted. The F-statistic also shows a jointly statistical significance of the set of explanatory variable included in the model in order to explain the inflation process.

Also in this case, we use the Newey-West covariance method in the estimation of the model in order to overcome problems of heteroskedasticity in the error terms, adjusting the standard errors in order to obtain better t-statistics.

In addition, the results from the Breusch–Godfrey test reported in table 9 below indicates that we fail to reject the null hypothesis of no evidence of serial correlation among the residuals in our hybrid Phillips curve model at 1 per cent significance level.

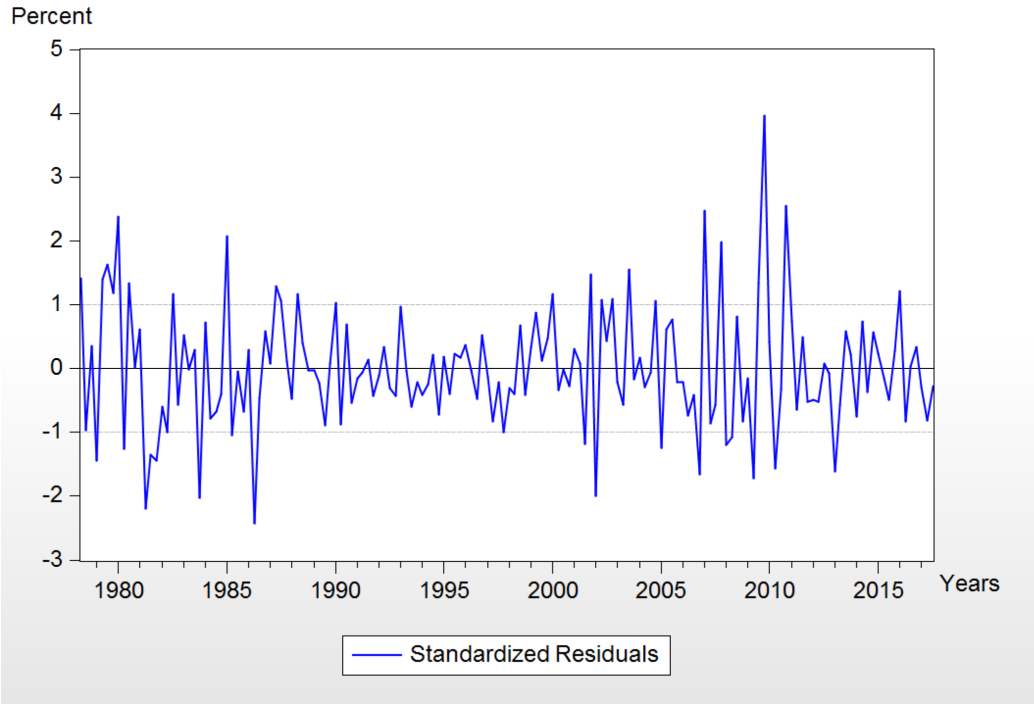
Table 11. Breusch–Godfrey serial correlation test of the estimated hybrid Phillips curve

F-statistic	3.3132	Prob. F(12,131)	0.0003

Source: own elaboration

Figure 12 below further shows the stationarity structure of the standardized residuals of the dependent variable of our new specification model equation. However, if we compare the path of the residuals of both our models, we can clearly see that the hybrid Phillips curve equation model implied a more instable behavior among the respective residuals, with major deviations during the 1980-86 period, the 2002s, the 2007-08 period, and the 2010-11 period. Overall, we can conclude that our aforementioned belief regarding the use of a survey in order to measure inflation expectations has been implicitly confirmed. In fact, the inclusion of the expected inflation introduced a higher degree of noise in the estimation model.

Figure 12. Behavior of the residuals from the estimated hybrid Phillips Curve

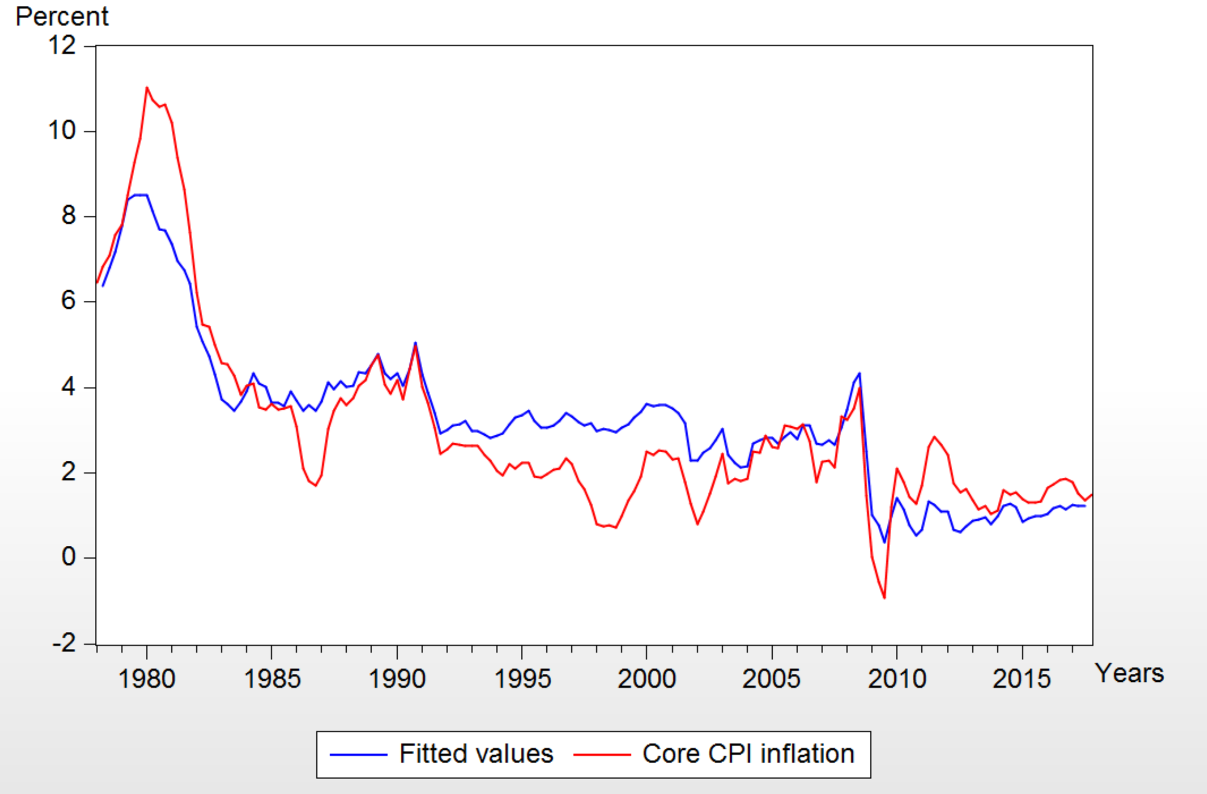


Source: own elaboration
Note: Standardized residuals path over the 1978:II to 2017:III sample period.

4.3.2 DYNAMIC TRACKING PERFORMANCE OVER THE 1978:II to 2017:III

Figure 13 below displays the dynamic tracking performance of our new specification model. The graph clearly shows that the Phillips curve performs really well over the entire sample period. In the 1980s the actual core CPI inflation is roughly 2% higher than the estimated inflation on average, while for the 1994-2000 the actual inflation is around 2% lower that the estimated inflation on average. Finally, from the 2000s until the end of the 2017s we can clearly see an overall good performance of our estimated model of the Phillips curve, thus confirming the relative stability of the Phillips curve over the recent period.

Figure 13. Dynamic Simulation of Core CPI hybrid Phillips Curve Estimated over 1978:I to 2017:III

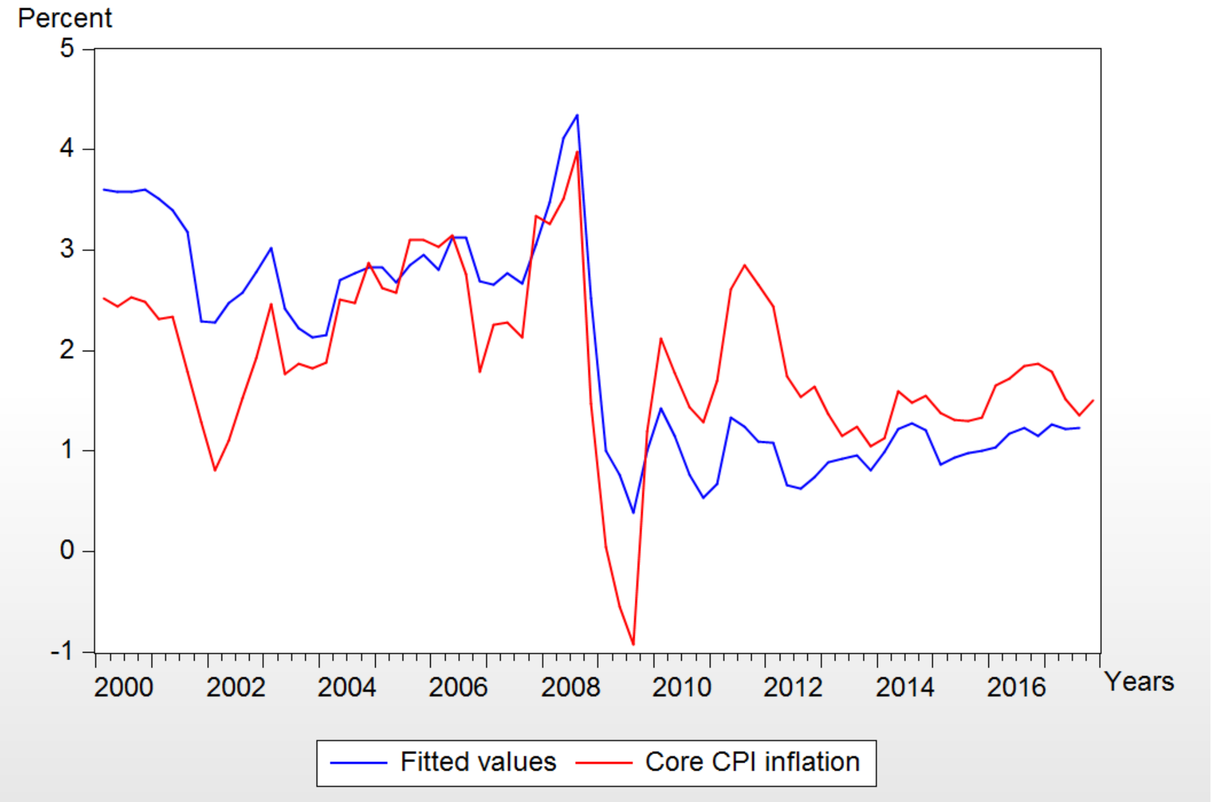


Source: own elaboration.

Note: Dynamic simulation forecast of the Consumer Price Index excluding food and energy, seasonally adjusted, U.S. Bureau of Labor Statistics. The fitted values are the parameters estimated from the base specification model only for the 1978:I to 2017:III period.

Having a look in more details on the behavior of the hybrid Phillips curve, we provide a more detailed dynamic simulation of the estimated model over the period 2000:I to 2017:IV , as displayed in figure 14 below. The estimated Phillips curve overestimate actual inflation for the 2000-02 period, while performing really well during the 2004-2009 period. For the last seven years we can see that actual core CPI inflation is roughly less than 1 per cent above the estimated inflation on average, while returning back on track in the last three years. Therefore, in this case, we can deduct that the dynamic tracking performance of our new estimation model performed pretty well during the recent period in order to capture the current path of the core CPI inflation in the United States. However, we have also to highlight a decreasing performance of the dynamic simulation of this model in the current period with respect to the previously backward-looking model that incorporated labor share income as a measure of labor market slack. The reason probably lies in the way expected inflation has been measured, reflecting a certain degree of noise in the estimated model.

Figure 14. Dynamic Simulation of Core CPI Phillips Curve Estimated over 2000:I to 2017:III



Source: own elaboration.

Note: Dynamic simulation forecast of the Consumer Price Index excluding food and energy, seasonally adjusted, U.S. Bureau of Labor Statistics. The fitted values are the parameters estimated from the hybrid model only for the 1978:I to 2017:III period.

4.3.3 MODEL STABILITY OVER THE 1984:II to 2011:IV

We conduct a Quandt-Andrews breakpoint test in order to test for the presence of possible structural breaks. The results reported in table 12 below indicate at least one structural break in our base specification model, and that the most likely date refers to the third quarter of 2009, most likely due to the wake of the financial crisis during that period. However, it is possible that further structural breaks could result in other periods as well. Therefore, in order to directly test the stability of the expectations component of the hybrid Phillips curve, we perform a Chow test choosing the same range of period as we did for the base specification model. The correspondent results displayed in table 13 below indicate that we fail to reject the null hypothesis of parameter stability for the pre and post 2008 period at one per cent significance level. Therefore, as a further confirmation of the stability of the Phillips curve in the United States, we can conclude that the inclusion of inflation expectations into our hybrid Phillips curve maintained intact the evidence against the Lucas' critique, again.

Table 12. Quandt-Andrews unknown breakpoint test for the estimated hybrid Phillips curve

Statistic	Value	p-value
Maximum LR F-statistic (2009Q3)	2.4119	0.0363

Null Hypothesis: No breakpoints within 15% trimmed data

Test Sample: 1984Q2 2011Q4

Number of breaks compared: 111

Source: own elaboration

Note: probabilities calculated using Hansen's (1997) method

Table 13. Chow Breakpoint Tests centered around last quarter of 2008 for the estimated hybrid Phillips curve

Breakpoints	F-statistic	Prob. F(15,128)
2008 Q3	2.0668	0.0155
2008 Q4	2.2065	0.0091
2009 Q1	2.3373	0.0055
2009 Q2	2.3318	0.0056

Null Hypothesis: No breaks at specified breakpoints

Source: own elaboration.

5. CONCLUSIONS

After having conducted the estimation of three different specifications adopted in order to model the Phillips curve, the main empirical results of this thesis highlight a well and alive Phillips curve in the United States. Due to the overall good dynamic tracking performances of all our three models in showing a stable Phillips curve that doesn't wonder off track over a long period of time, our findings implicitly suggest that the Phillips curve should be strongly taken into account for policy purposes, in particular in capturing and understanding changes in the domestic inflation process. Furthermore, these findings assume an even strong connotation by looking at the stability of the estimated parameters coefficients of our Phillips curve model specifications in the occurrence of important shifts in monetary policy that were supposed to affect the U.S. inflation.

We first estimated a traditional model of the Phillips curve whose main results suggests changes in the core CPI inflation that have become less sensitive to labor market tensions, implying a flattening Phillips curve slope. In this context, we assume that this finding turn out to be caused by a situation, on the labor market side, where workers are not able anymore to exercise their bargaining power in order to obtain higher wage rates, even when there are tightening labor market conditions.

We also changed the base specification model because the estimated Phillips curve didn't capture really well the low path of the core CPI inflation dynamics during the last five years. Therefore, we decided to replace the unemployment rate with labor share of income as a proxy of firms' real marginal costs. We did this because a different measure of economic slack in the model would have be more appropriate in capturing the dynamics between changes in inflation. Moreover, we decided to include a different measure of labor market slack due to the supposition that labor share income have showed a relatively similar path of inflation during the last decade, thus potentially representing a key factor in the explanation of the inflation process. Our suggestion resulted indeed correct, with a consequent better dynamic tracking performance of the correspondent estimated modified Phillips curve model in predicting the core CPI inflation during the entire sample period, in particular for the recent period (2014-2017).

Finally, we estimated a hybrid Phillips curve by explicitly including a forward-looking component of inflation in the model mainly due to the fact that the previous two models fails to provide evidence of an inflation that equalizes expected inflation in the long-run, implying only a short-run trade-off between changes in inflation and economic slack. The main result in this case suggests that the inclusion of a measure of expected inflation reflects a core CPI inflation that reacts more persistently to long-lasting shocks in the economy, however highlighting a more pronounced flattening of the Phillips curve slope.

Overall, the results of the first two models highlight a core CPI inflation that is mainly driven by its own past year values, denoting that a certain degree of price inertia in the U.S. economy still strongly affects the future path of inflation. The same idea applies to our hybrid Phillips curve model, where we have seen that the combination of a simultaneous one per cent increase in the percentage changes of both backward and forward-looking components of inflation resulted in an almost one-to-one relationship with respect to the changes in its actual value. By implication, this situation reflects a more stable conduction of monetary policy pursued by Federal Reserve, mainly over the last decade, with its relative inflation-targeting at the 2 per cent level.

As a further final remark, we can conclude that, even if we provide evidence of a still stable short-run trade-off between inflation and economic slack during the recent period in the United States, the main macroeconomic relationship underlying the Phillips curve framework seems to highlight a situation where inflation dynamics have become less sensible to labor market tensions over time.

6. APPENDIX

Table 14. – Unit root test unemployment rate in level

		t-Statistic	p-value
Augmented Dickey-Fuller test statistic		-4,3953	0.0004
Test critical values:	1% level	-3.4540	
	5% level	-2.8718	
	10% level	-2.5723	

Null Hypothesis: unemployment rate has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=15)

Table 15. – Unit root test core CPI inflation after first differencing

		t-Statistic	p-value
Augmented Dickey-Fuller test statistic		-7.3526	0.0000
Test critical values:	1% level	-3.4547	
	5% level	-2.8722	
	10% level	-2.5725	

Null Hypothesis: core CPI inflation has a unit root
Exogenous: Constant
Lag Length: 11 (Automatic - based on SIC, maxlag=15)

Table 16. – Unit root test import prices after first differencing

		t-Statistic	p-value
Augmented Dickey-Fuller test statistic		-12.2502	0.0000
Test critical values:	1% level	-3.4540	
	5% level	-2.8718	
	10% level	-2.5723	

Null Hypothesis: import prices has a unit root
Exogenous: Constant
Lag Length: 5 (Automatic - based on SIC, maxlag=15)

Table 17. – Unit root test labor share income in level

		t-Statistic	p-value
Augmented Dickey-Fuller test statistic		-21.1904	0.0000
Test critical values:	1% level	-3.4541	
	5% level	-2.8719	
	10% level	-2.5724	

Null Hypothesis: labor share income has a unit root

Exogenous: Constant

Lag Length: 0 (Automatic - based on SIC, maxlag=15)

Table 18. – Unit root test expected inflation after first differencing

		t-Statistic	p-value
Augmented Dickey-Fuller test statistic		-4.9398	0.0001
Test critical values:	1% level	-3.4737	
	5% level	-2.8805	
	10% level	-2.5769	

Null Hypothesis: expected inflation has a unit root

Exogenous: Constant

Lag Length: 5 (Automatic - based on SIC, maxlag=13)

Table 19. – Modified "Triangle-model" Phillips Curve Estimates: Quarterly Inflation Rate, CPI excl. Food and Energy

Variable	Coefficient	t-Statistic	p-value
α_0	0.2455	2.1512	0.0324
	(0.1141)		
$\Delta\pi_{t-1}$	0.3915***	6.3921	0.0000
	(0.0613)		
$\Delta\pi_{t-2}$	0.1192*	1.9136	0.0568
	(0.0623)		
$\Delta\pi_{t-3}$	0.1968***	3.9003	0.0001
	(0.0505)		
$\Delta\pi_{t-4}$	-0.4842***	-6.2887	0.0000
	(0.0770)		
U_t	0.0180	0.1428	0.8866
	(0.1263)		
U_{t-1}	-0.4019	-1.7093	0.0886
	(0.2351)		
U_{t-2}	0.3341	1.3042	0.1933
	(0.2562)		
U_{t-3}	0.1388	0.6950	0.4877
	(0.1997)		
U_{t-4}	-0.1310	-1.6085	0.1089
	(0.0815)		
Δp_t	-0.0245	-1.3790	0.1691
	(0.0178)		
Δp_{t-1}	-0.0104	-0.5011	0.6168
	(0.0208)		
Δp_{t-2}	-0.0284	-2.0242	0.0440
	(0.0140)		
Δp_{t-3}	0.0750***	5.3370	0.0000
	(0.0141)		
Δp_{t-4}	0.0459***	4.5364	0.0000
	(0.0101)		
Included observations	275		
R-squared	0.5743		
Adjusted R-squared	0.5514		
F-statistic	25.0577		
Prob(F-statistic)	0.0000		

Asymptotic standard errors for the parameter estimates are reported in parentheses.

* Significant at the 10 per cent level.

**Significant at the 5 percent level.

***Significant at the 1 percent level.

Source: estimated parameters are own elaboration.

Table 20. Modified Phillips Curve Estimates: Quarterly Inflation Rate, CPI excl. Food and Energy (two more lags of labor share income and its current value have been added)

Variable	Coefficient	t-Statistic	p-value
α_0	0.0059	0.2153	0.8297
	(0.0275)		
$\Delta\pi_{t-1}$	0.4349***	8.3285	0.0000
	(0.0522)		
$\Delta\pi_{t-2}$	0.1232**	2.2247	0.0270
	(0.0554)		
$\Delta\pi_{t-3}$	0.2007***	3.8231	0.0002
	(0.0525)		
$\Delta\pi_{t-4}$	-0.5050***	-10.7443	0.0000
	(0.0470)		
W_t	0.0150	0.5357	0.5926
	(0.0280)		
W_{t-1}	0.0492*	1.7055	0.0893
	(0.0288)		
W_{t-2}	0.0617**	2.1262	0.0344
	(0.0290)		
W_{t-3}	0.0103	0.3549	0.7230
	(0.0291)		
W_{t-4}	-0.0185	-0.6530	0.5143
	(0.0284)		
Δp_t	-0.0217	-1.3630	0.1741
	(0.0159)		
Δp_{t-1}	-0.0102	-0.6097	0.5426
	(0.0167)		
Δp_{t-2}	-0.0308*	-1.6925	0.0918
	(0.0182)		
Δp_{t-3}	0.0753***	4.4081	0.0000
	(0.0171)		
Δp_{t-4}	0.0428**	2.5665	0.0108
	(0.0167)		
Included observations	274 after adjustments		
R-squared	0.5434		
Adjusted R-squared	0.5187		
F-statistic	22.0138		
Prob(F-statistic)	0.0000		

Asymptotic standard errors for the parameter estimates are reported in parentheses.

* Significant at the 10 per cent level.

**Significant at the 5 percent level.

***Significant at the 1 percent level.

Source: estimated parameters are own elaboration.

Table 21. Modified Hybrid Phillips Curve Estimates: Quarterly Inflation Rate, CPI excl. Food and Energy

Variable	Coefficient	t-Statistic	p-value
α_0	0.1279	1.0833	0.2805
	(0.1180)		
$\Delta\pi_{t-1}$	0.3195***	3.8614	0.0002
	(0.0827)		
$\Delta\pi_{t-2}$	0.1478*	1.7629	0.0801
	(0.0838)		
$\Delta\pi_{t-3}$	0.1211**	2.0200	0.0453
	(0.0599)		
$\Delta\pi_{t-4}$	-0.4566***	-7.7359	0.0000
	(0.0590)		
$\Delta\pi_{t-5}$	0.1645**	2.3572	0.0198
	(0.0698)		
$\Delta\pi_{t-6}$	0.1785***	2.7463	0.0068
	(0.0650)		
U_t	-0.0960	-0.8136	0.4172
	(0.1179)		
U_{t-1}	-0.2926	-1.3539	0.1779
	(0.2161)		
U_{t-2}	0.5033**	2.1996	0.0295
	(0.2288)		
U_{t-3}	0.1284*	0.5521	0.5817
	(0.2326)		
U_{t-4}	-0.2653**	-2.1730	0.0315
	(0.1221)		
Δp_t	-0.0213*	-1.9043	0.0589
	(0.0112)		
Δp_{t-1}	-0.0022	-0.1770	0.8598
	(0.0121)		
Δp_{t-2}	-0.0265*	-1.9420	0.0541
	(0.0136)		
Δp_{t-3}	0.0429***	3.0699	0.0026
	(0.0140)		
Δp_{t-4}	0.0281**	2.0612	0.0411
	(0.0136)		
$\Delta\pi^e_{t+1}$	0.2841***	4.5462	0.0000
	(0.0625)		
Included observations	158 after adjustments		
R-squared	0.6763		
Adjusted R-squared	0.6370		
F-statistic	17.2061		
Prob(F-statistic)	0.0000		

Asymptotic standard errors for the parameter estimates are reported in parentheses.

* Significant at the 10 per cent level.

**Significant at the 5 percent level.

***Significant at the 1 percent level.

Source: estimated parameters are own elaboration.

Table 22. Chow Breakpoint Tests centered around last quarter of 1979 for the estimated base specification model

Breakpoints	F-statistic	Prob. F(12,251)
1979 Q3	2.5183	0.0038
1979 Q4	2.5292	0.0037
1980 Q1	2.6904	0.0020
1980 Q2	3.3552	0.0001
1981 Q1	3.6807	0.0000

Null Hypothesis: no breaks at specifics breakpoints

Source: own elaboration

Table 23. Chow Breakpoint Tests centered around last quarter of 1979 for the estimated modified base specification model

Breakpoints	F-statistic	Prob. F(12,251)
1979 Q3	2.2338	0.0108
1979 Q4	2.2506	0.0102
1980 Q1	2.3006	0.0085
1980 Q2	2.7473	0.0016
1981 Q1	2.7801	0.0014

Null Hypothesis: no breaks at specifics breakpoints

Source: own elaboration

7. REFERENCES

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