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Dissecting the Determinants of Inflation in the US

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Abstract

This paper studies the determinants of inflation in the US under a VAR modeling approach, using Granger causality tests and out-of-sample performance comparisons, to provide a deeper analysis for asset management. It is demonstrated that after correcting for structural changes, both money supply and real activity measures have merit in determining inflation. More importantly, the paper shows how decisive it is for asset managers to understand the ways structural changes affect these traditional transmission mechanisms and how to take them into account in order to be able to timely assess inflation trends.

Keywords: Inflation, Money Supply, Real Activity, Granger Causality

Introduction

Inflation is a phenomenon of great importance to all economic agents, as a general price increase, or decrease, has repercussions on several dimensions, from consumer purchasing power and savings to debt burdens and competitiveness of domestic products. Moreover, the lack of price stability distorts its function of conveying supply and demand information, thus perturbing economic decisions. Therefore, it is a crucial factor for asset managers, in particular those managing longer term macro strategies. It is in such context that this paper, developed as part of a Directed Research Internship with Banco de Investimento Global (BiG), aims to provide a detailed analysis over several economic variables and relationships commonly used to forecast inflation, in order to understand what truly drives inflation across macroeconomic contexts. This necessity arises from the fact that different methods of forecasting, grounded on various theoretical or empirical backgrounds, have performed differently through time, signaling the importance of assessing how structural changes influence the inflationary process. Such is accomplished by breaking down the transmission mechanisms of these relationships to verify its theoretical validity in practice through an econometric analysis of causality, followed by forecasting performance comparisons between a commonly used benchmark and the models proposed in this paper, as additional confirmation. Ultimately, the intent is to provide insight on the inflation drivers in the US to contribute to an informed and profitable asset allocation by asset managers. In particular, it is an especially relevant topic at a time when inflation has been interestingly low and stable in the last decade – despite several indicators pointing otherwise – and at a time of highly sensitive monetary policy shifts.

The paper is structured as follows: a literature review covering the timeline of forecasting methods that sets up consequent hypotheses (pp. 4-7); a specific focus on the relationship between money supply and inflation, and then between real activity measures and inflation (pp.

7-12); an empirical analysis of relevant relationships (pp. 13-20); and finally a discussion and closing remarks (pp. 20-22).

Literature review

The literature on this topic is vast, covering different forecasting approaches that stem from a disagreement on what truly causes inflation. Various schools of thought have formulated theories of inflation, with the main strands being either Keynesian or Monetarist inspired. Keynesian schools posit that inflation can result from excessive aggregate demand growth relative to aggregate supply growth – demand-pull inflation –, from a supply shock due to higher costs of production – cost-push inflation –, and from expectations that past inflation will persist coupled with the price/wage spiral – built-in inflation (Gordon, 1988). Monetarist schools, on the other hand, describe inflation as an event originating from greater money supply growth relative to output growth, and thus, as an exclusively monetary phenomenon (Friedman, 1963). Because of this, several model specifications have been proposed to forecast inflation, most of which showing inconsistent performance across sample periods and inflation measures.

Papers such as Stock and Watson (1999) demonstrate the predictive reliability of Phillips curve specifications, an approach based on empirical observation by Phillips (1958) that uses real activity measures to forecast inflation, for one-year-ahead forecasts compared to a simple univariate benchmark. Notably, the authors demonstrate the superior performance of using a Phillips curve model based on a composite activity index, as well as no advantage from including money supply measures. Several critics to Phillips curve predictive capabilities have been documented in the literature, a peremptory example of such being Atkeson and Ohanian (2001), which compares textbook NAIRU and Stock and Watson (1999) specifications with a random walk model on 12-month inflation and finds superior performance of the naïve approach. Benkovskis *et al.,* (2011) assesses the link between real activity and inflation and finds that this relationship has changed over time with correlations peaking during recessions and shocks to inflation being rather persistent, especially since the 1990s, when Phillips curve specifications started to lose their predictive power. Furthermore, it finds that the sharper the shock to inflation, the longer its effects will influence price levels – such was the case for the last financial crisis. The breakdown of this correlation, on the other hand, appears mostly during recoveries, when both high unemployment and high productivity and prices coexist (Quévat and Vignolles, 2018). Smets and Wouters (2007) argue that such behavior is likely due to lower volatility of shocks themselves, rather than due to fundamental changes, which indicates a need to observe stronger real activity oscillations before it is possible to verify its repercussions on price level. It has been, in fact, extensively noted in the literature that conventional Phillips curve relationships have weakened since the 1990s. Some papers have verified this widespread idea that the Phillips curve has flattened between the 1970s and 1990s, and remained stable since then (Blanchard, Cerutti and Summers, 2015). Importantly, Stock and Watson (2008) recognize the univariate model superiority in forecasting but show evidence of the relevance of equating real activity measures to inflation at turning points – at which we are presently. This point highlights the crucial need to understand what fundamentally drives inflation across structural shifts and that univariate outperformance is likely to be circumstantial rather than ultimately superior. For instance, some of the opposition to Phillips curve models is based on an apparent decoupling of productivity and wage growth since the 1990s. Schwellnus, Kappeler and Pionnier (2017) argue that when correcting for greater wage inequality and decreasing labor share, this decoupling is no longer present. Moreover, Anderson (2007) substitutes the commonly used average hourly earnings measure by total compensation, to reflect increased relevance of variable pay relative to base salary in recent history, and finds a closer proximity between both variables. Quévat and Vignolles (2018) further include productivity to enrich estimates of this relationship.

The role of money in forecasting, in turn, is still upheld by a solid body of literature. In particular, authors argue for not only high correlation at low frequencies, but also leading properties of money over inflation in low frequency data for longer-term forecasts, defending its predictive value (Assenmacher-Wesche and Gerlach, 2008a, 2008b; Azevedo and Pereira 2010; Lanne, Luoto and Nyberg, 2014). The long run predictive power of money measures is widely accepted, but its usefulness in short run forecasting is a subject of debate. Papers such as Woodford (2007a) and Binner *et al.* (2009), argue that monetary aggregates either have no predictive power or improvements based on them are only marginal compared to simple random walk models. The latter refers to Atkeson and Ohanian (2001) in search for an explanation for this pattern, citing the difficulty of forecasting not only inflation, but also various other economic variables since the 1980s, proposing also an alternative reasoning – that monetary aggregates may be less informative when inflation is low and stable.

Despite the above mentioned findings, Ang, Bekaert and Wei (2007) conducted a large comparative analysis of forecasting models, from simple random-walk models to Phillips curve specifications and combined forecasts, and found that survey data outperforms all other specifications for CPI measures, whereas PCE measures were shown to follow simple random-walk specifications, and in both cases, Phillips curve models were outperformed. This study was mostly done through simple linear regression analysis using OLS and for one-year ahead forecasts. In order to mitigate the apparent inconsistency, combined forecasts and alternative methods have also been tested, from simple means to time-varying parameters and Bayesian dynamic model averaging (Koop and Korobilis, 2009), as well as bagging methods (Inoue and Kilian, 2007).

Overall, all methods appear to be very unreliable for definitive usage, indicating that the inflation process is much too complex to be grasped in a single econometric method. It is because of this uncertainty in modeling inflation that this paper attempts to provide a robust fundamental analysis of the main inflation drivers to reinforce econometric forecasts.

Determinants of Inflation

On Money Supply

The emphasis on monetary aggregates started to give way to other methods of inflation forecasting in the late 1980s, where a disconnection between money supply growth and inflation first became apparent. Up until then, excess money growth was highly correlated and exhibited a leading relationship with inflation over longer horizons, a relationship that since then has broken down. This can be broadly demonstrated by plotting 10-year moving averages of both variables, with 1990 as the turning point (Chart 1). Specifically, correlations between long averages of excess money growth and inflation measures up to the 1990s were as high as 91%, before heavily inverting since then – although for the whole sample correlations are still relevant, standing around 60%. Velocity of money, which had been fairly stable until then, also started exhibiting a much more unpredictable behavior precisely when the connection appears to have diverted – an argument used by opponents of traditional Monetarism, as stable velocity is one of its assumptions – which can also be seen in Chart 1.

Testing these relationships with different money definitions – such as MZM – leads to similar conclusions, as the bulk of these aggregates are measures shared by all of them. However, it can be argued that money has become increasingly hard to define as innovations in the financial markets have made it difficult to distinguish what truly is money used in real economy transactions. Said phenomenon may be attributed in part to an increasing relevance of the financial sector and, recently, to the subdued effect of the Fed’s extra liquidity on prices. With increased financial sector preponderance, there is a larger money leakage to the financial system that may not translate into injection in the real economy. This consubstantiates in the following pattern: the financial sector has since the 1980s surged in percentage of total GDP, as financial innovations attracted more and more capital, incentivized leveraging and contributed to asset price surges that are not captured by standard inflation measures, based on goods and services. In itself, this pattern should not translate into a real economy deceleration, on the contrary, it should contribute to faster and broader investment throughout non-financial sectors. However, data shows a growing gap of financial to real assets (Chart 2, as a ratio of financial to total assets), a factor that is coupled with higher industry concentration and market power that leads to higher profit margins without increasing productivity – aspects that will be covered in the next section.

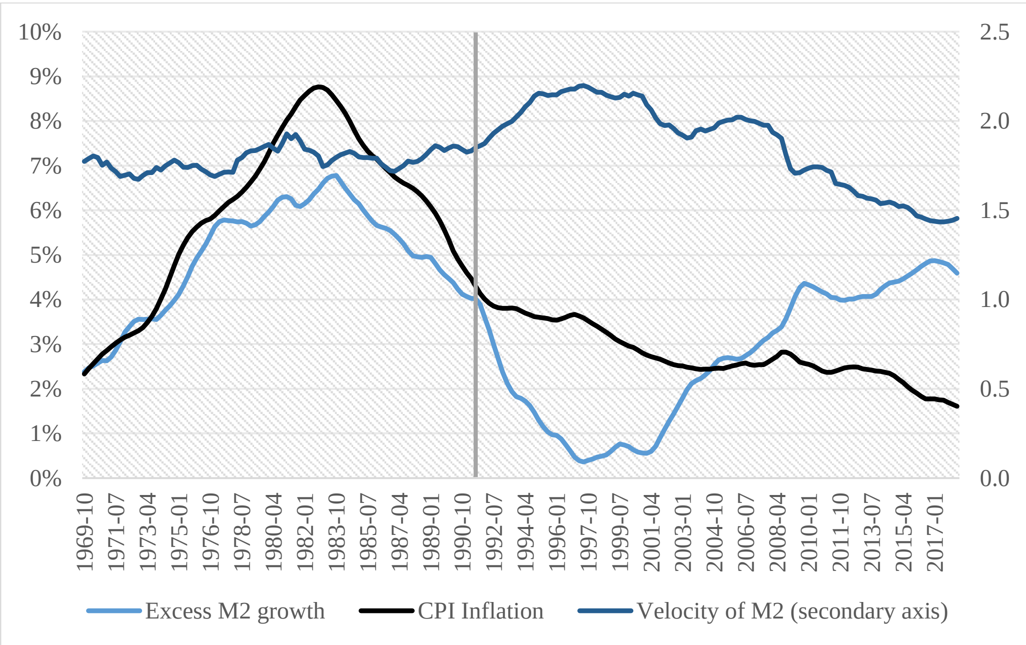
It is possible to visualize this phenomenon by looking at measures such as velocity of money or money multipliers. Assumed to be stable in the equation of exchange[1], velocity of money is a good indicator of imbalances in the transmission mechanism from money supply to prices. In fact, and giving special attention to the unprecedented increase in money supply since the great financial crisis, a large part of the extra liquidity from quantitative easing has remained within the money market. Theory would indicate that increasing money supply should increase banks' reserves, which in turn reduces the federal funds rate since demand for money is lower and supply is larger. With lower costs of capital, banks should be extending more credit, contributing to more spending and investment, and consequently, inflation. On the contrary, banks have retained much of this extra liquidity as excess reserves – to levels without historical precedent that have remained high since the beginning of quantitative easing, in large due to interest payments by the Fed on these reserves –, and have been notably more conservative in extending credit – delinquency rates on credit card loans, for instance, dropped to historical lows –, thus having a minimal effect on inflation. The diminished effect could also come from a higher personal saving rate – or money hoarding –, however, data shows the personal saving

[1] Equation of Exchange: Money Supply × Velocity = Price × Quantity

rate at relatively low levels. Velocity of money therefore reflects this, continuing the steady decline since the 1990s, with a large drop during the last crisis, as well as the various money multipliers – money stock measures such as M2 divided by the Monetary Base – which have similarly reached all-time lows.

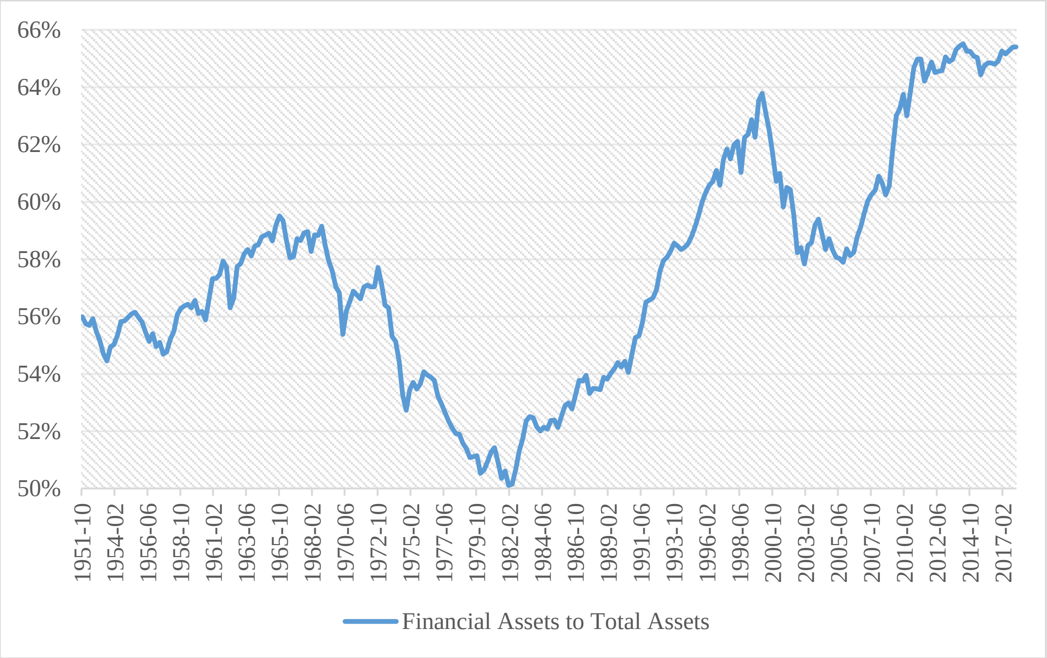
In conclusion, it is hypothesized that it is not that money has no longer a tight connection with inflation, but rather that it is harder to measure effective money supply today than back in the height of Monetarism, and that recent increases in the monetary base have not translated into more available money for the real economy. For modeling purposes, the hypothesis is that we can use the velocity of money as a proxy of the imbalances in the theoretical money supply relationship with inflation, attaining stronger causality than with excess money growth as a sole predictor – as demonstrated in the Empirical Analysis section.

Chart 1 – 10Y Moving Avg. of Excess M2 Growth and CPI inflation rate (Velocity on secondary axis)



Source: Author’s calculations using FRED data

Chart 2 – Financial Assets to Total Assets of Nonfinancial Business, Households and Nonprofits



Source: Author's calculations using FRED data

On Real Activity

Traditional Phillips curve specifications establish a relationship between inflation, past inflation, unemployment gap and variables to control for supply shocks. However, in a broader sense, it is any relationship between real aggregate activity and inflation (Stock and Watson, 1999). As discussed in the literature review above, many Phillips curve specifications have been supported and refuted, and as such, in this paper an attempt is made to deconstruct the most commonly tested relationships to determine whether they are ultimately useless or if they have simply suffered structural changes that need to be accounted for.

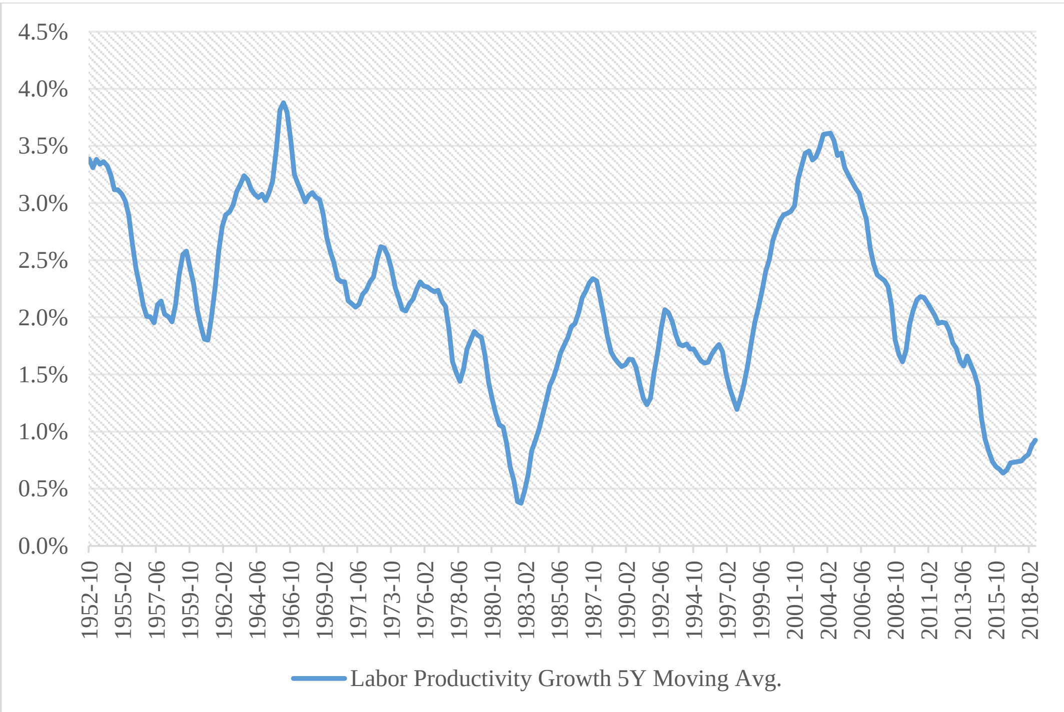
Starting with the most well-known relationship, this paper studies unemployment and inflation. The way this relationship takes place relates to wage growth, capacity utilization and productivity. In theory, when the economy is highly productive, operating near maximum capacity and unemployment reaches significantly low levels – below the NAIRU – there is an upward pressure on wages, which then translates into an upward pressure on inflation through demand-pull. In the literature review above, various authors were mentioned with respect to modifications in this simple relationship in order to account for structural changes over time. These are taken into consideration in order to improve the analysis. In a similar way to what was done for money supply measures, some hypothesis related to real activity specifications are stipulated beforehand, that are then tested in the Empirical Analysis section, combining all of these insights from the literature.

The markedly reduced impact of real activity on price levels is hypothesized in this study to be related to low productivity growth levels and consequently modest wage growth, as well as to labor market trends with respect to worker distribution per sector. Low productivity growth levels in the US have been a trend in recent years that can be attributed to a decrease in corporate investment in tangible and knowledge-based capital, which in turn is likely to derive from an uncertain policy environment and constraints on the housing and credit markets. Corporate investment has dropped all across developed countries and has showed a very modest recovery, with much of the US business community focusing on less asset-heavy sectors – a fact that, while partly due to technology sector growth, can be attributed to less confidence in the business environment. Furthermore, industry concentration has been growing since the 1990s, with lower competition between firms and larger chunks of market share flowing to fewer groups. This consolidation, in turn, leads to the high profit margins that have been recorded recently, but which do not derive from increased productivity (Chart 3). Adding to this scenario is the labor force trend, which shows a decrease in labor force participation due to ageing population, and a shift of added jobs towards low productivity sectors such as Healthcare and Social Assistance. The recent low productivity scenario may also be connected with the money market. With more conservative credit policies and greater emphasis on the short term by corporations, innovations are slower to be implemented, the mismatch of skills that was aggravated by the financial crisis is only slowly corrected and companies invest less in riskier, more disruptive projects.

Other factors that signal overheating in an economy are capacity utilization and the unemployment gap. In the US, capacity utilization has been peaking at consistently lower levels since the 1970s and the unemployment rate is just now dropping below the consensual long run sustainable level. When these variables stay off their overheating levels, real activity does not impact inflation as much, given the incentive to continue hiring before there is an upward pressure on wages.

In the section below, an econometric analysis is developed on the hypothesis presented above using insights from the literature review.

Chart 3 – Smoothed Annual Labor Productivity Growth (5Y Moving Avg.)



Source: Author's calculations using FRED data

Empirical Analysis

In this section, data description, summary statistics and stationarity tests are presented for all variables used in econometric analysis, then separate causality tests are conducted regarding money supply measures and real activity measures, leading to the specification of a few models based on the conclusions drawn beforehand, and finally to an out-of-sample performance comparison between the proposed models and a common benchmark.

Data and Summary Statistics

All data series used directly or posteriorly manipulated by the author are collected from the Federal Reserve Economic Data (FRED) website. The data has quarterly frequency and a maximum sample size of 282 observations, corresponding to 1948Q1:2018Q2. As a measure of the relevant variable – inflation rate – the Consumer Price Index (CPI) is preferably used, as there is a wider range of comparable forecasting methods based on it. The chosen measure of money definition is the M2 monetary aggregate for similar reasons – widespread usage by practitioners and the Fed. Two measures of wage growth are studied in order to assess differences in base wage growth versus total compensation growth. All variables that constitute percent changes are presented on a year-on-year basis – inflation, average hourly earnings and total compensation growth, and excess M2 growth –, the remaining percent unit variables are level – unemployment rate, capacity utilization and yield curve spread. Detailed information on all variables can be found in Table 1.

Methodology

In this paper, the chosen method for modeling inflation is the Vector Autoregressive (VAR) model, in which variables are arranged in a set of linear dynamic equations whose number is the same as the number of variables, meaning each variable at a time is modeled as dependent – on an equal number of its own lags and lags of other variables. This method is useful to model economic data in the sense that it captures intertemporal dependencies between variables, allowing us to assess causality through structural changes. As a requirement to implement this approach, it is necessary to ensure that variables enter the model in a stationary form, either level or after differencing. To do so, the Augmented Dickey-Fuller Test (ADF) is run on each variable, whose results can be found in Table 2. (Note that differenced variables will be prefixed by a "d" from this point on.) As a base criteria for null hypothesis rejection, the 5% significance level is used throughout the paper. Every test and modeling procedure presented along this section is performed in STATA.

Table 1 – Data description and summary statistics

Variable	Name	Unit	Obs	Mean	Std Dev	Min	Max
CPI Inflation Rate	cpi	%	282	3.51%	2.92%	-2.79%	14.43%
Excess M2 Growth	xm2	%	234	3.60%	3.15%	-3.47%	12.75%
Velocity of M2	vm2	ratio	238	1.81	0.18	1.43	2.20
Unemployment Rate	unrate	%	282	5.78%	1.63%	2.57%	10.67%
Average Hourly Earnings	ahe	%	214	4.17%	1.97%	1.42%	9.10%
Total Compensation	comp	%	282	1.54%	1.67%	-2.75%	5.35%
Labor Share	lbsh	index*	282	109.52	4.47	98.15	117.51
Labor Productivity Index	prod	index*	282	59.16	24.13	24.09	105.10
Housing Starts	houst	thousands	237	1432.70	391.08	525.67	2424.00
Total Capacity Utilization	tcu	%	206	80.27%	4.19%	67.12%	88.51%
Trade-Weighted Exchange Rate USD-Major	twfx	index*	182	129.17	19.34	95.36	194.79
10Y-2Y Yield Spread	spd	%	168	0.96%	0.91%	-1.28%	2.80%

*: 2012 as base year
Notes: Variables presented before modifications to enter econometric models.
Source: Author.

Table 2 – Augmented Dickey-Fuller Tests

Variable	Test Statistic	5% Critical Value	Stationarity
cpi	-2.889	-2.879	Level
xm2	-3.664	-2.881	Level
vm2	0.273 (-9.835)	-2.881	First difference
unrate	-2.020 (-7.682)	-2.879	First difference
ahe	-1.255 (-11.349)	-2.882	First difference
comp	-5.892	-2.879	Level
lbsh	-1.531 (-21.085)	-2.879	First difference
prod	2.238 (-15.871)	-2.879	First difference
houst	-2.255 (-12.282)	-2.881	First difference
tcu	-2.442 (-7.604)	-2.883	First difference
twfx	-1.482 (-9.733)	-2.885	First difference

spd	-2.327 (-10.719)	-2.886	First difference

Notes: A test statistic lower than the critical value means the null hypothesis of no stationarity is rejected. Test statistics between parentheses refer to test results after differencing.
Source: Author.

After ensuring stationarity, Granger causality tests are run on common model specifications and on modified specifications that result from the hypotheses formulated above and from test results, for the whole sample. In this phase, the analysis is once again segmented in money supply measures and real activity measures. All tested models follow this generalized specification for a multivariate VAR with p lags:

$$y_t = c + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + u_t \quad (1)$$

where each y_i, c and u_t are vectors of length equal to m variables and $A_1, \ldots, A_p$ are mxm matrices of coefficients for each lag $1, \ldots, p$.

Money Supply Measures – Causality Study

After using the ADF test on CPI inflation rate, excess M2 growth and velocity of M2, it is possible to see that the inflation rate and excess M2 growth are level stationary at the 5% significance level, whereas velocity is difference stationary.

The long run causality from money to prices is well documented; it is the short run that incites debate. Therefore, the interest lies in studying causality from money supply measures to inflation in the shorter run, which is assessed using Granger causality tests after specifying the data under a VAR model. The first relationship tested in this section is between CPI inflation and excess M2 growth, following the traditional model derived from the equation of exchange. Using the VAR lag selection procedure in STATA, all criteria indicate 2 as the number of optimal lags. Next, the data is modeled and the Granger causality test is run, which does not support causality from money growth to inflation for the whole sample (Table 3). Such is an expected result given the qualitative analysis of the previous section regarding a disconnection of money growth and prices.

However, when the equation is adjusted for the velocity of M2 – entering the model as first difference to ensure stationarity – in an attempt to reflect effective money supply reaching the real economy, and repeat the process above, the corresponding Granger test after a VAR (6) shows strong causality, at the 1% significance level. This supports the hypothesis of a connection between money supply and price level, as long as this relationship has an effective impact on the real economy. Both of these specifications meet the stability, normality and no autocorrelation criteria, tested using the eigenvalue, Jarque-Bera and Lagrange multiplier tests, respectively.

Table 3 – Granger causality tests for money supply measures

Equation	**Excluded**	**Chi2**	**df**	**Prob > Chi2**
cpi	xm2	1.1436	2	0.565
	ALL	1.1436	2	0.565
cpi	xm2	29.805	6	0.000
	dvm2	24.856	6	0.000
	ALL	37.341	12	0.000

Notes: A probability below the 5% significance level means the null hypothesis of no Granger causality is rejected.
Source: Author.

Real Activity Measures – Causality Study

Once more the ADF test is run, and out of the used variables, unemployment rate, average hourly earnings growth, labor productivity, labor share, housing starts, total capacity utilization, trade-weighted exchange rate and 10y-2y yield spread are first difference stationary, whereas total compensation growth is level stationary.

Using a VAR model approach as above, and starting by testing the usual unemployment rate to inflation relationship, an optimal lag length of 2 is selected by all criteria. Both significance and causality from the unemployment rate to inflation are found. Using an alternative specification that explores the transmission mechanism through wage growth, and a VAR with an optimal lag of 6, no causality is found when using average hourly earnings, but the opposite happens when using total hourly compensation, in a VAR (2) – confirming the hypothesis found in the literature. In effect, using total compensation as a sole predictor rather than adding to the unemployment rate leads to a better model taking into account the diagnosis tests for stability and autocorrelation. In contrast, it is also demonstrated in this paper that adjusting for labor share or productivity does not further improve the model. The hypothesis made is that total compensation already reflects these two effects, as confirmed by running a Granger causality test between these variables, which means productivity, labor share – and consequently, wage inequality – are key drivers of inflation, albeit indirectly. These tests can be found in Table 4. All specifications meet the criteria of no autocorrelation, normality and stability of the VAR model.

Table 4 – Granger causality tests for real activity measures

Equation	Excluded	Chi2	df	Prob > Chi2
cpi	dunrate	13.354	2	0.001
	ALL	13.354	2	0.001
cpi	dahe	6.6069	6	0.359
	ALL	6.6069	6	0.359
cpi	comp	16.342	2	0.000
	ALL	16.342	2	0.000
cpi	comp	23.177	4	0.000
	dlbsh	3.2624	4	0.515
	dprod	1.5809	4	0.812
	ALL	31.728	12	0.002
comp	cpi	7.2425	4	0.124
	dlbsh	36.881	4	0.000
	dprod	32.693	4	0.000
	ALL	64.005	12	0.000

Source: Author.

Numerous other activity measures have been used in the literature as augmented Phillips curve models. Demonstrating the best results, according to Ang, Bekaert and Wei (2007), are specifications using Housing Starts, Trade-Weighted Exchange Rate, Yield Spreads and Total

Capacity Utilization. After running Granger causality tests to each variable when added to the best Phillips curve specification from above, it is demonstrated that Total Capacity Utilization and the 10Y-2Y Yield Spread contribute the most to the model. When jointly added, these variables are also shown to Granger cause inflation (Table 5). This gives support to the hypothesis stipulated above that capacity utilization has a connection with inflation by putting pressure on wages when at its peak, which then creates a pressure to increase price levels. Furthermore, it also provides preliminary evidence that the yield curve slope is still a good predictor, although a few peculiarities are presented later on this matter, regarding late sample structural changes.

Table 5 – Granger causality tests for augmented Phillips curve specifications

Equation	**Excluded**	**Chi2**	**df**	**Prob > Chi2**
cpi	comp	9.8403	2	0.007
	dhoust	1.3761	2	0.503
	ALL	10.796	4	0.029
cpi	comp	16.189	6	0.013
	dtcu	20.274	6	0.002
	ALL	38.548	12	0.000
cpi	comp	4.8336	2	0.089
	dtwfx	3.4532	2	0.178
	ALL	9.742	4	0.045
cpi	comp	8.1522	3	0.043
	dspd	24.264	3	0.000
	ALL	32.325	6	0.000
cpi	comp	8.5071	3	0.037
	dtcu	12.302	3	0.006
	dspd	24.213	3	0.000
	ALL	47.051	9	0.000

Source: Author.

Assessing Predictive Performance as Additional Support to Causality

In this section, forecasting models drawn from all conclusions made until this point are proposed and tested against a common benchmark – the simple random-walk model where inflation is determined solely by its own lags plus a random shock. Summarizing the models defined throughout the previous section, we have: (a) – money supply model with excess M2 growth and velocity of M2 as predictors; (b) – the simple Phillips curve model with total compensation growth as sole predictor; (c) – an augmented Phillips curve model which adds total capacity utilization and the 10y-2y yield spread to the previous specification; and finally (d) a joint model combining all predictors defined above. These models are estimated once in-sample and then resulting coefficients are used to predict the expected year-on-year inflation rate in the next quarter. For each model, this prediction is computed using estimations for the equation corresponding to CPI inflation – the first out of the whole set of $y_1, \dots, y_m$ dependent variables that result from running a VAR (p) model – as follows:

$$E_t(y_{1,t+1}) = c_1 + a_{1,1}^1 y_{1,t} + \cdots + a_{1,m}^1 y_{m,t} + \cdots + a_{1,1}^p y_{1,t-p+1} + \cdots + a_{1,m}^p y_{m,t-p+1} \quad (2)$$

where $y_{1,t+1}$ is the year-on-year inflation rate for quarter $t+1$, c_1 is the estimated constant term, $a_{1,1}^1, \dots, a_{1,m}^p$ are the estimated coefficients for each variable $1, \dots, m$ at each lag $1, \dots, p$ relative to the dependent variable y_1, and $y_{1,t}, \dots, y_{m,t-p+1}$ are the variables $1, \dots, m$ at each lag $1, \dots, p$.

The criteria for in-sample to out-of-sample division was a simple 75%/25% rule, which gives different out-of-sample periods for each model due to different sample sizes of the variables. This is taken into account when comparing with the benchmark by using matching out-of-sample periods between each model and the benchmark. Table 6 provides out-of-sample calculations of the Relative Root Mean Squared Errors (RRMSE), meaning the ratios of each model's RMSE divided by the benchmark's RMSE. In Appendix 1 it is possible to verify the stability of all these models and in Appendix 2 the normality and autocorrelation statistics. According to Stock and Watson (2001) on VAR models, coefficients are typically not reported given the model's complicated dynamics; Granger causality tests, for instance, are more informative. Here, the same line of thought is followed.

Overall, the models perform slightly better than the benchmark, giving support to the conclusions drawn above on what fundamentally causes inflation. Regarding the diagnosis tests of these models, no autocorrelation is found except on lags 2 and 3 of model (c) and on lag 4 of model (a). Normality is verified on all models except model (b). The implications are not severe; non-normality is common in economic data and given the large sample size it should not be a concern for Granger causality tests. With respect to autocorrelation, it could be argued that it is an issue for model (c), however the test is highly sensitive to lag length and the criteria used to choose an optimal lag length (AIC and BIC) do not aim to minimize autocorrelation – which could mean overfitting the data – but rather to maximize predictive performance.

Table 6 – Out-of-Sample Performance

Model	Out-of-Sample Period	Relative to benchmark RMSE
(a) Money Supply VAR (6)	2004Q2:2018Q2	0.893
(b) Phillips Curve VAR (2)	2001Q1:2018Q2	1.034
(c) Augmented Phillips Curve VAR (3)	2008Q2:2018Q2	0.946
(d) Joint Model VAR (9)	2008Q4:2018Q2	0.941

Source: Author.

Discussion and Closing Remarks

In the section above, various Granger causality tests were run following theoretical and empirical based specifications, under a VAR modeling approach. These tests provide evidence that inflation in the US is determined by its own lags, excess M2 growth, the velocity of M2, total compensation growth, total capacity utilization and the 10Y-2Y Yield Spread, which is also supported by good predictive performance out-of-sample. Although it is recognized that the models might exhibit biases, in general, the diagnosis tests support the models and the good out-of-sample performance using different samples for each, indicate a solid empirical result.

These results show an improvement over their respective traditional specifications – either theoretical or from empirical practice – which highlights an important point of this paper. The core hypothesis here presented was that inflation, as a very complex and non-linear process, can hardly be modeled by the same approach as structural changes happen in the economy that fundamentally change the way traditional transmission mechanisms affect prices. It is crucial that asset managers understand what drives inflation through structural changes, and for that it is necessary to understand what impact these changes have and how to correct the relationships accordingly. This paper has shown the main changes in the US inflationary process in the last decades:

- An imbalance in the money to prices connection resulting from a greater dominance of flows to the financial system that are not allocated to real investment and transactions, and, recently, a combination of tighter credit restrictions, slowly recovering balance sheets and central bank incentives that caused banks to keep unprecedented levels of excess reserves;
- A low labor productivity economy which, aggravated by wage inequality and lower labor share of income, disconnects output growth to price growth even for short term horizons.

These are symptomatic of highly developed economies, and as such, moderation in economic variables including inflation is likely to remain in the near future.

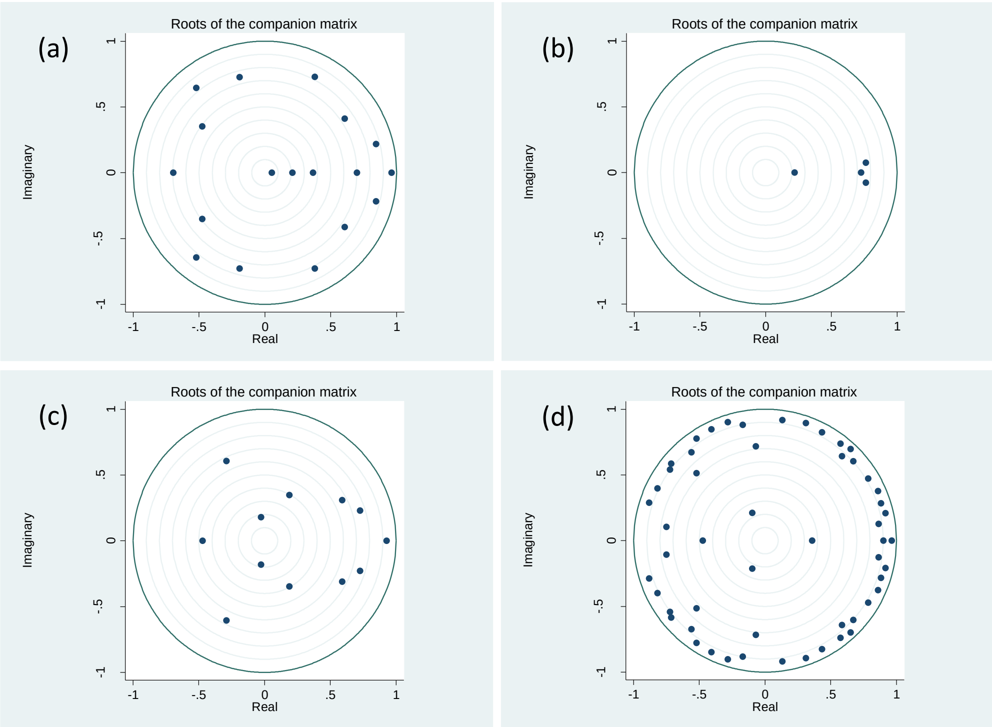
Additionally, it was demonstrated that total capacity utilization contributes to inflation by intensifying the transmission mechanism from activity measures to prices and that the yield spread is a good predictor. On the latter, a few remarks are in order. Causality tests are run for the whole sample in this paper, and therefore, some positive bias can exist, mitigating late sample structural changes. Such is the case for the yield curve slope; recently, while the spread has decreased significantly, it has to be noted that the Fed had been offering assets across several maturities in large amounts, affecting both the slope and level of the curve. It is thus more of a structural construct rather than a reflection of expectations, at least until a reversal to conventional monetary policy.

Going forward, a few aspects are of major relevance for asset managers with respect to the US. The effect of reversing quantitative easing and, more importantly, excess reserves, must be carefully monitored due to its lack of comparable precedents. A few undesirable scenarios could take place; the Fed is likely to raise interest rates, ease credit restrictions and reduce incentives on holding reserves very gradually in order to prevent excessive inflationary pressures, however, a sudden growth spur might incentivize banks to loan their readily accessible reserves, leaving the Fed with little or no timing to react. On the other hand, an economic downturn during this slow transition period would leave little room for the Fed to reduce rates if at that time they are still low. The productivity landscape will also be crucial, especially being a developed country such as the US. Since GDP growth is driven by two factors: productivity and labor hours/numbers, and given a decreasing weight of labor hours and workers on GDP growth, as seen in the labor market trends discussed previously, productivity becomes the core driver of GDP growth. As such, private investment in human capital and tangible assets are key drivers to monitor in order to assess the economy's ability to continue growing. These have shown an unimpressive trend in recent years.

Having screened through the major influences on inflation, this paper is concluded. It has demonstrated the importance of adjusting inflation's core drivers to structural changes, hopefully contributing to more informed investment decisions by asset managers.

Appendices

Appendix 1 – VAR Stability Tests



Notes: Eigenvalues below 1, i.e. within the circle, indicate VAR stability.
Source: Author.

Appendix 2 – VAR Autocorrelation and Normality Tests

	Probability > Chi2			
LM Autocorrelation Test per Lag	Model (a)	Model (b)	Model (c)	Model (d)
1	0.825	0.202	0.288	0.287
2	0.183	0.746	0.002	0.330
3	0.321	-	0.000	0.264
4	0.000	-	-	0.985
5	0.217	-	-	0.392
6	0.143	-	-	0.395
7	-	-	-	0.513
8	-	-	-	0.599
9	-	-	-	0.135
Jarque-Bera Normality Test	0.854	0.000	0.356	0.549

Notes: Probabilities below the 5% significance level mean the null hypothesis of normality/no autocorrelation is rejected.
Source: Author.

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