Revisiting the relationship between unexpected inflation and output in the presence of indexation

Pavlo Buryi
Harrisburg University of Science and Technology, Harrisburg, Pennsylvania, USA, and
Ficawoyi Donou-Adonsou
Department of Economics and Finance, John Carroll University, University Heights, Ohio, USA

Received 17 February 2019
Revised 10 August 2019
Accepted 10 September 2019

Abstract

Purpose – This paper aims to investigate the relationship between output and unanticipated inflation when wages are indexed for the loss of purchasing power. The authors argue that the monetary authority remains useful when firms that face rigid demand index wages to compensate for the loss of purchasing power, unlike Fischer (1977), who suggested that monetary policy loses effectiveness when firms index wages.

Design/methodology/approach – This paper develops a simple theoretical model followed by an empirical investigation of the relationship between output and unanticipated inflation in the presence of indexation. The theoretical model assumes a perfectly competitive firm that produces a final good that has no close substitutes using one factor, labor. The demand for the product is rigid. The empirical work considers quarterly US data from 1982Q1 to 2017Q1 and uses the Generalized Method of Moments in which endogenous variables are instrumented using their own lags. This paper further considers the period before and after the recent global financial crisis.

Findings – This paper shows that unexpected inflation decreases the growth rate of output in the USA. The decrease is quantitatively and qualitatively stronger before the financial crisis than after the crisis. This finding suggests that the Federal Reserve should maintain higher expectations of inflation and then surprise the public with lower inflation rates. The results further suggest that regardless of how expectations are formed, firms and workers agree on the nominal wage that is equal to the realized marginal revenue product of labor.

Originality/value – This paper sheds light on the behavior of the central bank and its relative ineffectiveness in light of the recent economic recession.

Keywords Monetary policy, Production, Inflation, Price level, Indexation, Unanticipated inflation, Output

Paper type Research paper

1. Introduction

In light of the recent economic recession, a lot of attention has been given to the Federal Reserve System and some economists have questioned the behavior of the central bank and its relative ineffectiveness. According to the expectations-adjusted supply function hypothesis, deviations of real output from trend can be induced only by unanticipated inflation, and that anticipated inflation cannot induce any significant effect[1]. Therefore, the

Journal of Financial Economic Policy
Vol. 12 No. 2, 2020
pp. 245-261

1757-6385
DOI 10.1108/JFEP-02-2019-0042

JEL classification – E52, L2, J3

effectiveness of monetary policy that aims to stimulate output depends on the relationship between unexpected inflation and output.

It is generally accepted that this relationship is positive, because of the presence of sticky nominal wages. This hypothesis was proposed by Lucas (1972) and tested by Blejer and Leiderman (1980), who find that unanticipated inflation leads to an increase in output and to a decrease in the rate of unemployment; these findings accord well with those reported by Lucas (1972), Sargent and Wallace (1975) and Barro (1978). Cukierman and Meltzer (1986) also provide a theoretical model that explains the incentive for a less conservative central banker to surprise the public by generating unexpected inflation for output gain purposes. Among other empirical studies, Darrat (1985) finds that the unanticipated component of inflation exerts a significant positive impact on real output in Canada. Perhaps more importantly, he reports that a sharp reduction in inflation (if unanticipated) could induce a two-year recession. Batchelor (1982) finds similar results for four major European economies – Belgium, France, Germany and Italy. Fackler and Parker (1990) test the effect of unanticipated and anticipated money on output for the USA and find that, unlike anticipated money growth, unanticipated money growth explains fluctuations in output for the period between the Civil war and the Great Depression. Thus, this study implies that unexpected inflation does affect output. Some studies find no evidence of such hypothesis. Dorval and Smith (2015) apply time-series methods to measure unexpected inflation for more than 20 countries using both retail and wholesale prices and find a significant, positive correlation between output growth and inflation for the entire period. However, they find little evidence that this correlation is caused by an underlying role for unexpected inflation. While Sheffrin (1979) finds no evidence in the USA, Sheehey (1984) finds little evidence in Latin American countries that unanticipated money growth has real effects. Fountas and Karanasos (2007) report mixed evidence regarding the relationship between unexpected inflation and output growth, suggesting inflation uncertainty may or may not be detrimental to output growth. Other studies, nonetheless, contend that there is a negative relationship between unexpected inflation and output growth. Evidence of such studies includes Jansen (1989), who investigates the negative relationship between inflation uncertainty and output growth in the USA and finds no support to such relationship. The lack of such relationship between unexpected inflation and output growth may imply that inflation is mostly predictable. Ball (1994) shows that the credible policy of disinflation causes booms. He concludes that it is the lack of "credibility" of the policy rather than disinflation itself that is the cause of prolonged recessions. Miller and Sutherland (1993) and Driffill and Miller (1993) arrive at the same conclusion. Daniels *et al.* (2019) find that reductions in wage and price stickiness diminish the tradeoffs between disinflations and output losses. Moreover, their findings indicate that higher levels of expected inflation allow policymakers to pursue "cold turkey" inflation reductions even more aggressively. Ascari and Rankin (2002) introduce microfoundations and use a dynamic general equilibrium model with staggered wages to show that disinflation, whether unanticipated or anticipated, unambiguously causes a slump.

The assumption of sticky nominal wages, however, may not be realistic. López-Villavicencio and Saglio (2017) find that wage-setting process is heterogeneous among countries. They find that nominal wage rigidities are more important in the USA, whereas wage indexation is dominant in European countries. Moreover, in some European countries indexation is a prescribed law (Adolph and Wolfstetter, 1991). More and companies in the USA choose to index wages in attempts to attract and retain the best candidates or as a part of other strategic initiatives such as corporate social responsibility. Moreover, in the USA, roughly 60 per cent of all unionized workers are covered by the cost of living adjustment or escalator clause. These types of wage adjustment mechanisms are known as indexation formulas. In the real world, indexing formulas typically index wages wholly or partially to the Consumer Price Index. Such formulas use current rates of inflation or operate with a lag. This lag could be caused by a delay in the publication of official statistics, and in practice, it is considerably short (McCallum, 1983).

Effectively indexation fixes real wages. There is a body of literature that studies the real effects of disinflation in the presence of real rather than nominal wage rigidities. Tesfaselassie (2019) finds that a credible, gradual disinflation leads to a delayed output slump along the transition path if real wage rigidities are sufficiently strong. Ascari and Merkl (2009) also analyze the cost of disinflations under real wage rigidities and take nonlinearities into account. They find that disinflations lead to a permanently higher level of output, and real wage rigidities increase the output during the adjustment to the new steady state. Ascari and Rossi (2011) add that in the presence of real wage rigidities, disinflation has opposite effects on output depending on the price-setting mechanism. They point out that in the Calvo pricing model, disinflation generates a long-lasting boom in output, whereas, in the Rotemberg model, it generates a moderate output slump. Ascari and Ropele (2012) report that the ability of nominal and real frictions to explain observed aggregate fluctuations depends on the degrees of price and wage indexation to past inflation.

Indexing wages to the price level has received quite a lot of attention in the literature. Gray (1976) uses a neoclassical model that embraces short-term wage rigidity and uncertainty and examines the role of wage indexation in reducing macroeconomic fluctuations. The model shows that indexation isolates the real sector from monetary shocks and makes real shocks worse. The author suggests a partial indexation that accounts for the stochastic characteristics of the economy. However, optimal indexing may not completely insulate the real sector from the effects of unanticipated monetary shocks (Gray, 1978). In a two-period framework, Fischer (1977) develops a rational expectations model with overlapping labor contracts that are signed for two periods. His model considers nonindexed wages to be sticky in the short-run, thus allowing monetary policy to affect real output in the short-run despite rational expectations. In other words, long-run labor contracts permit monetary policy to be effective even when the policy is fully anticipated – the anticipation is based on information that becomes available after the contract is signed. In the long-run, however, no effect on output is observed. He argues that indexed labor contracts are less attractive than nonindexed labor contracts, and monetary policy may lose their effectiveness if long-term contracts are indexed in a way that duplicates one-period contracts. This view finds supports from Christiano *et al.* (2005), who used a dynamic, general equilibrium model to highlight the importance of stickiness in nominal wages for expansionary monetary policy to deliver an expected outcome.

Other studies have argued that the choice of monetary policy rule will influence the degree of indexation. However, a policy rule, such as money stock or interest rate, which is combined with optimal wage indexing to the price level, will not deliver an optimal response to demand shocks or supply shocks. Such studies include Fethke and Policano (1981), Fethke and Jackman (1984) and Bradley and Jansen (1988). Bradley and Jansen (1989) will, however, show that the combination of nominal income targeting and optimal wage indexing provides the optimal monetary response to demand and supply shocks, irrespective of the elasticity of labor supply.

If indexation is viewed as a way to compensate for the loss of purchasing power, indexation can be itself inflationary. Fischer (1983) investigates the issue and finds that wage indexation, along with tax and bond indexations, increases the price level, and this positive association is in large part explained by monetary and fiscal policies rather than any inflationary shock such as the oil price shock. Blanchard (1979) has, however, argued that the effect of the oil price on the price level depends very much on the degree of indexing of the nominal wage to the price level.

This paper aims to provide a simple, yet concrete analysis of the effect of unanticipated inflation on output when the firm faces a rigid demand and wages are indexed for the loss of purchasing power. We argue that the monetary authority remains useful when firms index wages to compensate for the loss of purchasing power, unlike Fischer (1977), who suggests that monetary policy loses effectiveness when firms index wages. We show that unexpected inflation decreases the growth rate of output in the USA. The decrease is quantitatively and qualitatively stronger before the financial crisis than after the crisis. This finding has implications for monetary policy. The Federal Reserve should concentrate its efforts on maintaining higher expectations of inflation and then surprise the public with lower and possibly negative inflation rates. Our results further suggest that regardless of how expectations are formed, firms and workers agree on the nominal wage that is equal to the realized marginal revenue product of labor.

The remainder of this paper is organized as follows. In Section 2, we propose a theoretical model to explain the negative effect of unanticipated inflation when the wage is indexed for the loss of purchasing power. Section 3 presents data and methods. Section 4 tests the proposed theory empirically. In Section 5, we consider the impact of the global financial crisis. We run some robustness check in Section 6, while Section 7 concludes.

2. Theoretical model

To analyze the effect of unexpected inflation on output, a simple and yet effective theoretical model is developed. We consider a microeconomic model that consists of one perfectly competitive firm that produces a final good that has no close substitutes using one factor, labor.

The current level of output (X_t) is determined by the amount of labor hired in the same period (L_t). The following production function describes the manufacturing process:

$$X_t = AL_t, \tag{1}$$

where A is a productivity factor.

Since, it takes time to train labor before it can be productive, it may be difficult to immediately hire more workers of certain occupations and therefore increase output when economic circumstances demand it. Thus, the number of workers that the firm trains depends on firm's expectations of the future.

Nominal wages that workers earn (w_t) are set at the time t, when labor is hired, and are fully indexed for the loss of purchasing power compared to the previous period. Therefore, $t-1$ expectation of the nominal wage at time t equals to the wage at time $t-1$ corrected for expected inflation:

$$E_{t-1}[w_t] = \left(1 + E_{t-1}[\pi_t]\right) w_{t-1}, \tag{2}$$

where $E_{t-1}[\pi_t]\, w_{t-1}$ is expected increase in the nominal wage because of inflation[2].

The expected total cost of producing X_t units of output equals to:

$$E_{t-1}[TC_t] = \frac{\left(1 + E_{t-1}[\pi_t]\right) w_{t-1}\ X_t}{A}. \tag{3}$$

Moreover, the expected marginal cost of each additional unit of output is constant, and it is equal to:

$$E_{t-1}[MC_t] = \frac{(1 + E_{t-1}[\pi_t \ ])w_{t-1}}{A}. \tag{4}$$

Demand and price for good at time t are represented by X_t and P_t, respectively. We assume that our representative consumer has the following utility function:

$$U_t = \alpha \ X_t \ - \frac{\beta \ X_t^2}{2} + y_t, \tag{5}$$

where y_t is the consumption of the numeraire good.

From equation (5), we can derive the following inverse demand function:

$$P_t = \alpha - \beta X_t, \tag{6}$$

where, α is the maximum amount that a consumer is willing to pay for the good, whereas β is time-invariant slope of the inverse demand function; moreover, α, $\beta > 0$. This demand function remains unchanged when income of the representative consumer or the overall price level changes, implying demand rigidity.

When the firm decides how much labor to train, it bases the decision on the expectations of the future optimal output. To find expected optimal output, the firm sets expected future marginal cost, $E_{t-1}[MC_t]$, equal to expected future price, $E_{t-1}[P_t]$. Expected future price can be determined by using the linear inverse demand function and the value of expected output. Hence, time $t-1$ expectation of the price at time t could be described by the following equation:

$$E_{t-1}[P_t] = \alpha - \beta E_{t-1}[\ X_t]. \tag{7}$$

By using the expected future price, equation (7), and the expected marginal cost equation (4), we can find that the expected optimal output equals:

$$E_{t-1}[X_t] = \frac{\alpha}{\beta} \ - \frac{(1 + E_{t-1}[\pi_t])w_{t-1}}{A\beta}. \tag{8}$$

Equation (8) represents time t-1 expectation of the optimal output at time t. However, when actual inflation is realized, optimal output at time t may be different than what was expected at time t-1, since the actual rate of inflation may be different from what was expected. In fact, the realized optimal output at time t given by:

$$X_t = \frac{\alpha}{\beta} \ - \frac{(1 + \pi_t)w_{t-1}}{A\beta}. \tag{9}$$

Now suppose that X_t^* represents current output that the firm chooses to produce at time t. Since production of output may require some trained workers, firms may not be able to adjust their output because of the lack of skilled labor. If the firm is perfectly capable of adjusting its output, it will choose to produce $X_t^* = X_t$; however, if it is not capable of adjusting output, it will produce $X_t^* = E_{t-1}\,[X_t]$. Therefore, we can express current output as a linear combination of the realized optimal output and the expected optimal output, depending on whether or not the firm can adjust its output:

$$X_t^* = E_{t-1}[X_t] - \vartheta(E_{t-1}[X_t] - X_t), \tag{10}$$

where parameter ϑ captures the ability of the firm to adjust its output, and satisfies $0 \leq \vartheta \leq 1$. If the firm is fully capable of adjusting its output, $\vartheta = 1$, then it produces the realized optimal output, X_t; if it is not capable of adjusting its output, $\vartheta = 0$, then it chooses to produce the expected optimal output, $E_{t-1}[X_t]$. If the firm is partially capable of adjusting its output,$0 < \vartheta < 1$, then the value of the current output will be somewhere in-between the realized optimal and the expected optimal outputs. The better the firm is at adjusting its output, the closer is the value of the current output to the value of the realized optimal output.

By using equations (8) and (9), we can find the difference between the expected optimal and the realized optimal outputs, and then by using equation (10), we can get the following expression of the current output:

$$\begin{aligned} X_t^* &= E_{t-1}[X_t] - \vartheta \frac{(\pi_t - E_{t-1}[\pi_t])w_{t-1}}{A\beta} \\ &= \frac{\alpha}{\beta} - \frac{(1 + E_{t-1}[\pi_t])w_{t-1}}{A\beta} - \vartheta \frac{(\pi_t - E_{t-1}[\pi_t])w_{t-1}}{A\beta}. \end{aligned} \tag{11}$$

By taking the derivative of equation (11) with respect to $(\pi_t - E_{t-1}[\pi_t])$, we can study how exogenous changes in unanticipated inflation affect the level of current output:

$$\frac{\partial X_t^*}{\partial(\pi_t - E_{t-1}[\pi_t])} = -\frac{\vartheta(w_{t-1})}{A\beta} < 0. \tag{12}$$

According to equation (12), an exogenous increase in the rate of unanticipated inflation causes current output to fall. That is, output and unanticipated inflation are inversely related.

In the next section, we use the ordinary least squares (OLS) and generalized method of moments (GMM) methods to derive the parameters of the theoretical model and to test its predictions. However, before, we can move to the estimation, we have to impose a few restrictions on the wage that the firm and its workers have to agree on.

Since inflation causes prices of all goods to change at same rate, the price of the good that the firm produces is expected to go up by the same amount as the price of the labor that the firm hires. Hence, the expected future price at the time when labor is hired is equal to:

$$E_{t-1}[P_t] = (1 + E_{t-1}[\pi_t])P_{t-1}. \tag{13}$$

Regardless of how expectations are formed, the values of the future expected price have to be equal. That is:

$$\alpha - \beta E_{t-1}[X_t] = (1 + E_{t-1}[\pi_t])P_{t-1} = (1 + E_{t-1}[\pi_t])(\alpha - \beta X_{t-1}). \tag{14}$$

Equation (13) suggests that the price is expected to go up at the rate of the expected inflation. Since we argue that both ways of forming expectations concerning the future price produce the same result, [equation (13)] must be equal to the expected marginal cost, [equation (4)], as well:

$$(1+E_{t-1}[\pi_t])P_{t-1} = \frac{(1+E_{t-1}[\pi_t])w_{t-1}}{A}. \quad (15)$$

Equation (15) suggests:

$$w_{t-1} = AP_{t-1} = A(\alpha - \beta X_{t-1}) = A(\alpha - \beta AL_{t-1}), \quad (16)$$

that is, at the time when expectations are formed, nominal wage must be equal to the realized marginal revenue product of labor.

3. Data and methods

3.1 Data

To test our theoretical model, we use US data obtained from the St. Louis Federal Reserve website. The data set covers the period of time from 1982Q1 to 2017Q1. The following quarterly data series are used:

- real gross domestic product (GDP) (percentage change from a year ago) seasonally adjusted;
- inflation (percentage change in CPI from a year ago) seasonally adjusted; and
- average hourly earnings of production and nonsupervisory employees (total private, dollars per hour) seasonally adjusted.

To measure expected inflation, we interchangeably use two variables: University of Michigan Expected Inflation and Consumer Opinion Surveys.

The University of Michigan Expected Inflation series provides estimates of expected inflation at time t for the next 12 months. To find what inflation was expected a year ago to be now, one has to look at the value of the variable at time $t-4$ because we use quarterly data. The same is true for Consumer Opinion Surveys, $E_{t-4}[\pi_t] = COS_{t-4}$.

Also, it is important to recall that Michigan expected inflation series is not seasonally adjusted and has been seasonally adjusted by calculating the centered moving average, calculating and adjusting for seasonal indices and dividing the raw series by the adjusted seasonal indices.

The reason we use annual growth rates rather than percentage changes from period to period is that in the theoretical model the firm indexes wages and hires labor only once a year and not each quarter. It is also reasonable to assume that the economy consists of more than just one firm, and in each quarter, there is at least one firm that hires labor and indexes wages. Therefore, the use of quarterly percentage change from a year ago data is justified for our purposes.

To capture wages, we use the average hourly earnings of production and nonsupervisory employees. By using this series as well as inflation and expected inflation series, we can find expected indexation and actual indexation payments that the firm has to pay after inflation is realized. $(E_{t-4}[\pi_t])w_{t-4}$ is the expected indexation payment, while $\pi_t\, w_{t-4}$ is the actual indexation payment.

Table I reports the summary statistics and indicates an average hourly wage of $14.01. Also, the summary statistics show differences in the expected inflation as measured by the

Table I.
Summary statistics

Statistic	y	π	w	Mich	COS
Mean	2.69	2.82	14.01	3.11	3.98
SD	2.05	1.44	4.25	0.57	0.81
Min	−4.10	−1.60	7.74	1.10	1.50
Max	8.50	7.60	21.75	5.00	6.40
N. Obs	140	140	140	140	133

Notes: y-Real Gross Domestic Product, Per cent Change from Year Ago, Quarterly, Seasonally Adjusted Annual Rate; π-Consumer Price Index for All Urban Consumers: All Items, Per cent Change from Year Ago, Quarterly, Seasonally Adjusted; w-Average Hourly Earnings of Production and Nonsupervisory Employees: Total Private, Dollars per Hour, Quarterly, Seasonally Adjusted; Mich-University of Michigan: Inflation Expectation, Percent, Quarterly, Not Seasonally Adjusted. In Table I, however, the seasonally adjusted series' statistics are reported; COS-Consumer Opinion Surveys: Consumer Prices: Future Tendency of Inflation: European Commission and National Indicators for the United States, Net Per cent, Quarterly, Seasonally Adjusted

University of Michigan and the Consumer Opinion Surveys, the latter being on average higher than the former. It is worth mentioning that although actual inflation is sometimes negative, expected inflation is always positive.

3.2 Method

To test whether proposed theory is valid, we estimate the following regression:

$$y_t = \Gamma + \Upsilon\left(1 + E_{t-4}[\pi_t]\right)w_{t-4} + Z\left(\pi_t - E_{t-4}[\pi_t]\right)w_{t-4} + \varepsilon_t, \tag{17}$$

where $\Gamma = \frac{\alpha}{\beta}$, $\Upsilon = -\frac{1}{A\beta}$ and $Z = -\frac{\vartheta}{A\beta}$. The error term, ε_t, has conditional expectation equal to zero. That is, $E(\varepsilon_t | z_t) = 0$, where z_t is any set of instruments.

Consistent with the theoretical model, in equation (11), we empirically regress growth rate of output on the expected indexation adjusted nominal wage ($(1 + E_{t-4}[\pi_t])w_{t-4}$) and the difference between the expected and actual indexation payments that the firm must pay after inflation is realized. We expect $\Upsilon < 0$ because as the expected cost of production goes up, the quantity produced should go down. We also expect $Z < 0$ because if the amount of indexation that the firm has to pay is greater than what it had anticipated, the actual cost of production becomes greater than what the firm had anticipated and therefore it will reduce its output. Once we know Υ and Z, we can find ϑ, the ability of the firm to adjust its output in response to unexpected inflation.

To account for autoregressive nature of the growth rate of real GDP, we control for its first lag. The final equation that is estimated takes the following form:

$$y_t = \Gamma + \Upsilon\left(1 + E_{t-4}[\pi_t]\right)w_{t-4} + Z\left(\pi_t - E_{t-4}[\pi_t]\right)w_{t-4} + \Theta y_{t-1} + \varepsilon_t. \tag{18}$$

To estimate equation (18), we use the GMM estimator developed by Hansen (1982), which is heteroskedastic and autocorrelation consistent. We suspect a reverse causality between the dependent (output growth) and the two independent variables (wage indexed to expected inflation and the unexpected indexation payment). To that end, we use a set of instruments for the right-hand side variables. Beyer *et al.* (2007) argue that a small number of instruments may cause the GMM estimates to suffer from weak identification problem. Therefore, they use nine instruments – three lags of inflation, output gap and nominal interest rate variables – to estimate monetary policy rule. Their results suggest that more of past economic conditions produce better GMM estimates, implying that more instruments are relevant for the endogenous variables. In this paper, in addition to using the constant term as an instrument, we use three lags of each endogenous variable as instruments.

The GMM chooses the parameter estimate $\hat{\theta}$ that solves the following minimization problem:

$$min_{\hat{\theta}}\ \hat{m}(\theta)' W \hat{m}(\theta) \tag{19}$$

where $\hat{m}(\theta)$ is the sample moment vector and W is the optimal weighting matrix. The moment conditions used are derived from the first-order condition of equation (18), which is the expectation at time t of the error term given the instrument z_t. The law of iterated expectation is then applied to derive the moment condition for different instruments, which is then set equal to zero. These moment conditions will provide the basis for estimating the parameters in equation (18). As a check for the model's validity, we will run the test of over-identifying restrictions via Hansen's J statistic:

$$J = n\hat{m}(\theta)' W \hat{m}(\theta) \tag{20}$$

The J-statistic follows a chi-square distribution under the null hypothesis of model validity, with degrees of freedom equal to the number of over-identifying restrictions.

4. The empirical results

To begin, we test the series for the presence of unit root. The Augmented Dickey-Fuller (ADF) unit root test and the Phillips and Perron (PP) unit root test with constant and trend show that all series are stationary. The unit root tests are reported in Table II.

The empirical results are presented in Table III in which we report both the OLS (Columns 1 and 3) and the GMM estimates (Columns 2 and 4). In Columns 1 and 2, the results are based on consumer opinion surveys' expectations of inflation. When the wage is indexed to inflation, both expected cost, which is associated with expected inflation, and unexpected cost, which is associated with unexpected inflation, have a negative effect on output growth. Specifically, the OLS results indicate that a one-percentage point increase in unexpected cost decreases the growth rate of output by 0.01 percentage point. This impact is statistically significant at 5 per cent level and is qualitatively and quantitatively stronger

Variable	AIC lag selection for ADF test	Augmented Dickey-Fuller	Phillips-Perron
$(1+COS_{t-4})w_{t-4}$	3	−3.752** (0.019)	−4.833*** (0.000)
$(1+Mich_{t-4})w_{t-4}$	2	−5.494*** (0.000)	−4.076*** (0.000)
$(\pi_t - COS_{t-4})w_{t-4}$	3	−4.372*** (0.002)	−4.164*** (0.005)
$(\pi_t - Mich_{t-4})w_{t-4}$	2	−5.722*** (0.000)	−4.484*** (0.002)
Growth rate of GDP	3	−5.631*** (0.000)	−3.771** (0.018)

Notes: We report the Dickey-Fuller test statistic for the ADF test and the tau test statistic for the PP test. For Phillips and Perron unit root test, the number of lags chosen is four lags and is based on the Newey-West algorithm int{4(T/100)^(2/9)}. MacKinnon approximate p values are in parentheses. ***rejects at 1%; **rejects at 5%; * rejects at 10%

Table II. Unit root tests with constant and trend

Table III.
The empirical results

Dependent variable \ Method	(1) OLS Growth rate of GDP	(2) GMM Growth rate of GDP	(3) OLS Growth rate of GDP	(4) GMM Growth rate of GDP
Independent variable				
$(1+COS_{t-4})w_{t-4}$	−0.020*** (0.006)	−0.016 (0.015)		
$(1+Mich_{t-4})w_{t-4}$			−0.021*** (0.006)	−0.021*** (0.008)
$(\pi_t - COS_{t-4})w_{t-4}$	−0.010** (0.004)	−0.017*** (0.005)		
$(\pi_t - Mich_{t-4})w_{t-4}$			−0.008** (0.004)	−0.017*** (0.005)
$(Growth\ rate\ of\ GDP)_{t-1}$	0.850*** (0.057)	1.034*** (0.206)	0.847*** (0.055)	0.897*** (0.069)
Constant	1.578*** (0.468)	0.647 (1.538)	1.509*** (0.418)	1.329** (0.585)
R^2	0.821		0.822	
Hansen's J p-value		0.771		0.665
Number of observations	137	137	140	140

Notes: Columns (1) and (2) use expected inflation based on consumer opinion survey, whereas Columns (3) and (4) use expected inflation based on the University of Michigan estimates. GMM estimates are based on a two-step GMM estimation with a weight matrix that is heteroskedasticity and autocorrelation (HAC) consistent. The lag order is automatically selected using Newey and West's (1994) optimal lag-selection algorithm. At the exception of the lag of the dependent variable, three lagged values of each independent variable plus the constant term are used as instruments. ***rejects at 1%; **rejects at 5%; *rejects at 10%; robust standard errors are in parentheses in Columns (1) and (3), HAC standard errors are in parentheses in Columns (2) and (4)

with the GMM estimator. However, we do not see a significant evidence that the expected cost has negative effect on output growth when the GMM estimator is applied (Column 2).

The alternative specification uses the University of Michigan expected inflation, and the results are reported in Columns 3 and 4. The alternative specification confirms the previous results when expected inflation is based on consumer opinion surveys. More importantly, all the coefficients are statistically significant for both the OLS and GMM estimates, meaning both anticipated cost associated with anticipated inflation and unanticipated cost caused by unanticipated inflation have a negative effect on output growth. The striking result, however, is the magnitude of the unanticipated cost coefficient across the two specifications when the GMM estimator is applied (Columns 2 and 4). Put differently, a one-percentage point increase in unanticipated cost caused by unanticipated inflation decreases the growth rate of output by 0.017 percentage point regardless of the specification.

Using these empirical results[3] and equation (17), one can derive the parameters of the model shown in equation (9). With $\Upsilon = -0.021 = -1/A\beta$, and $Z = -0.017 = -\vartheta/A\beta$, it follows that $\vartheta = 0.81$. $\vartheta = 0.81 > 0$ is consistent with the theoretical model and suggests that firms adjust labor demand in reaction to unexpected inflation to reduce output.

Although the OLS high R^2 statistics suggest good fit of the model, the Hansen J-test of over-identifying restrictions suggests the models are valid with p values above the conventional significance levels. The GMM results are robust to the inclusion of higher lag orders as instruments[4]. The results thus provide strong evidence that the proposed theoretical model is valid, and indeed, unanticipated inflation reduces the growth rate of real GDP, through an increase in the cost of labor.

5. The global financial crisis

In this section, we test the stability of the model over the period of study. The sample period comprises the global financial crisis of 2007 that raises concerns about whether coefficient estimates are stable over time. To address this issue, we divide our sample into two sub-periods:

(1) the period before crisis (from 1982Q1 to 2007Q2); and

(2) the period after crisis (from 2007Q3 to 2017Q1).

Many economists accord with the fact that the recent financial crisis is the worst financial crisis since the Great Depression. Although the crisis peaked up in 2008, it is largely believed that it started in the third quarter of 2007 with the subprime mortgage crisis. In consequence, we re-run the regressions using the period before and after the third quarter of 2007. In general, our results remain robust to subdivisions in the time period. More specifically, when the wage is indexed for the loss of purchasing power, unanticipated inflation has a negative impact on output growth. Although this result remains very significant over the pre-crisis period (Table IV), it is less significant in the post-crisis period with respect to the GMM results (Table V, Column 2). The only exception where this significant impact is not seen is when inflation expectation is measured using the University of Michigan methodology as shown in Table V, Column 4.

With respect to the GMM results in Tables III, IV and V, Column 2, we observe that the magnitude of the impact of unanticipated inflation on output growth is smaller over the entire sample period than over the period before and after the crisis, that is, –0.017 (Table III, Column 2) versus –0.034 (Table IV, Column 2) and –0.027 (Table V, Column 2). Thus, the post-crisis period shows less response of output growth, unlike the pre-crisis period, to unexpected inflation. Although it can be argued that the small sample size in Table V (between 35 and 38 observations) may have contributed to reducing the impact of unanticipated inflation on output growth, one can regard this weak evidence or lack of it as firms being unable to fire a lot of workers post-crisis because of labor contracts that are signed and the existence of unions in some industries. Before the crisis, an employee might

Dependent variable \ Method	(1) OLS Growth rate of GDP	(2) GMM Growth rate of GDP	(3) OLS Growth rate of GDP	(4) GMM Growth rate of GDP
Independent variable				
$(1+COS_{t-4})w_{t-4}$	−0.031*** (0.009)	−0.014 (0.021)		
$(1+Mich_{t-4})w_{t-4}$			−0.030*** (0.011)	−0.015 (0.016)
$(\pi_t-COS_{t-4})w_{t-4}$	−0.027*** (0.009)	−0.034** (0.015)		
$(\pi_t-Mich_{t-4})w_{t-4}$			−0.027*** (0.008)	−0.027*** (0.009)
$(Growth\ rate\ of\ GDP)_{t-1}$	0.850*** (0.056)	0.978*** (0.126)	0.853*** (0.055)	0.935*** (0.079)
Constant	1.976*** (0.587)	0.594 (1.595)	1.873*** (0.615)	0.928 (1.017)
R^2	0.812		0.812	
Hansen's J p-value		0.474		0.379
Number of observations	102	102	102	102

Notes: Columns (1) and (2) use expected inflation based on consumer opinion survey, whereas Columns (3) and (4) use expected inflation based on the University of Michigan estimates. GMM estimates are based on a two-step GMM estimation with a weight matrix that is heteroskedasticity and autocorrelation (HAC) consistent. The lag order is automatically selected using Newey and West's (1994) optimal lag-selection algorithm. At the exception of the lag of the dependent variable, three lagged values of each independent variable plus the constant term are used as instruments. ***rejects at 1%; **rejects at 5%; *rejects at 10%; robust standard errors are in parentheses in Columns (1) and (3), HAC standard errors are in parentheses in Columns (2) and (4)

Table IV. The empirical results: pre-crisis period 1982Q1 to 2007Q2

Table V.
The empirical results: post-crisis period 2007Q3 to 2017Q1

Dependent variable \ Method	(1) OLS Growth rate of GDP	(2) GMM Growth rate of GDP	(3) OLS Growth rate of GDP	(4) GMM Growth rate of GDP
Independent variable				
$(1+COS_{t-4})w_{t-4}$	−0.021 (0.019)	−0.055** (0.026)		
$(1+Mich_{t-4})w_{t-4}$			−0.047* (0.027)	−0.039 (0.040)
$(\pi_t - COS_{t-4})w_{t-4}$	−0.004 (0.007)	−0.027* (0.015)		
$(\pi_t - Mich_{t-4})w_{t-4}$			−0.004 (0.006)	−0.011 (0.011)
$(Growth\ rate\ of\ GDP)_{t-1}$	0.863*** (0.119)	1.509*** (0.366)	0.852*** (0.121)	1.004*** (0.091)
Constant	1.997 (1.729)	3.248 (2.428)	3.823* (2.119)	2.823 (2.962)
R^2	0.762		0.770	
Hansen's J p-value		0.904		0.624
Number of Observations	35	35	38	38

Notes: Columns (1) and (2) use expected inflation based on consumer opinion survey, whereas Columns (3) and (4) use expected inflation based on the University of Michigan estimates. GMM estimates are based on a two-step GMM estimation with a weight matrix that is heteroskedasticity and autocorrelation (HAC) consistent. The lag order is automatically selected using Newey and West's (1994) optimal lag-selection algorithm. At the exception of the lag of the dependent variable, three lagged values of each independent variable plus the constant term are used as instruments. ***rejects at 1%; **rejects at 5%, *rejects at 10%; robust standard errors are in parentheses in Columns (1) and (3), HAC standard errors are in parentheses in Columns (2) and (4)

easily find another job if fired, in which case he or she would take the severance pay and leave, but the chance of finding another job is almost zero with the crisis, in which case the employee would prefer to stay until the expiration of the contract. The same logic would hold up for a union member.

Following Elliott and Müller (2006), we perform an efficient test for general persistent time variation in regression coefficients. The test contrasts a stable regression model from the unstable alternative. The general test has good power and size even in a heteroskedastic context. Under the null hypothesis, all regression coefficients are fixed over the sample period. The number of lags used in computing the long-run variance matrix is chosen using the Bayesian information criterion. This test is flexible in that it can allow some coefficients to be fixed over time while keeping others variable. Thus, assuming that the coefficient of the lag dependent variable is fixed over time, the general test (not reported here) shows that we fail to reject at the conventional significance levels the null hypothesis that the coefficients of expected inflation and unexpected inflation are fixed over the sample period 1982Q1-2017Q1. Next, we allow all regression coefficients to change over time, and the test rejects the null only at 10 per cent level of significance. All things considered, the model seems to be stable and consistent with the pre- and post-crisis analyzes.

6. Controlling for the oil price

Following the discussion in the literature, we control for the oil price. The increase in oil price may create inflationary pressure and reduce output. The oil price data is the average quarterly, not seasonally adjusted Spot crude oil price: West Texas Intermediate (percentage change from a year ago) provided by the St. Louis Fed. We deseasonalized the quarterly oil price by calculating the centered moving average and seasonal indices and following the methodology described above for the University of Michigan expected inflation. Also, we check for the presence of a unit root, and both the ADF and PP test with constant and trend results reject the null hypothesis of unit root. The OLS and GMM results, reported in Table VI, are

Dependent variable \ Method	(1) OLS Growth rate of GDP	(2) GMM Growth rate of GDP	(3) OLS Growth rate of GDP	(4) GMM Growth rate of GDP
Independent variable				
$(1 + COS_{t-4})w_{t-4}$	−0.020*** (0.006)	−0.020** (0.009)		
$(1 + Mich_{t-4})w_{t-4}$			−0.021*** (0.006)	−0.028*** (0.009)
$(\pi_t - COS_{t-4})w_{t-4}$	−0.010** (0.005)	−0.017*** (0.006)		
$(\pi_t - Mich_{t-4})w_{t-4}$			−0.009* (0.005)	−0.013* (0.007)
Oil price	−0.000 (0.004)	0.008 (0.006)	0.000 (0.004)	0.005 (0.006)
(Growth rate of GDP)$_{t-1}$	0.850*** (0.057)	0.896*** (0.110)	0.847*** (0.055)	0.704*** (0.065)
Constant	1.578*** (0.470)	1.346 (0.836)	1.527*** (0.427)	2.348*** (0.521)
R^2	0.821		0.822	
Hansen's J p-value		0.719		0.759
Number of observations	137	134	137	134

Notes: Columns (1) and (2) use expected inflation based on consumer opinion survey, whereas Columns (3) and (4) use expected inflation based on the University of Michigan estimates. GMM estimates are based on a two-step GMM estimation with a weight matrix that is heteroskedasticity and autocorrelation (HAC) consistent. The lag order is automatically selected using Newey and West's (1994) optimal lag-selection algorithm. At the exception of the lag of the dependent variable, three lagged values of each independent variable plus the constant term are used as instruments. ***rejects at 1%; **rejects at 5%; *rejects at 10%; robust standard errors are in parentheses in Columns (1) and (3), HAC standard errors are in parentheses in Columns (2) and (4)

Table VI. The empirical results (controlling for oil price)

similar to the previous findings; most notably unexpected inflation has a negative effect on output growth in the presence of indexation. We do not, however, find any evidence that oil price change affects output growth. This latter result seems to contradict the historical view that oil price upsurge was one of the factors behind the US recession in the 1970s, but aligns with Kilian (2008), who reported resilience of the US economy to oil price shocks. The resilience comes from the fact that there is an offsetting effect of higher oil prices and higher commodity prices on real output. Baumeister and Peersman (2013) also reported modest effects of oil price on output, whereas Kilian and Vigfusson (2017) showed that not all oil price increases appear to have been followed by recessions.

7. Additional controls

In this section, we take a step further to examine the relationship between unexpected inflation and growth in light of other controls. Following Eggoh and Khan (2014), factors such as financial development, investment, trade openness and government expenditure may have significant impacts on the relationship between inflation and growth. We account for this possibility and control for these variables. Financial development variable is measured by money aggregate M2 (as per cent change from year ago, quarterly, seasonally adjusted), investment is measured by gross fixed capital formation (as per cent change from year ago, quarterly, seasonally adjusted), government expenditure is government total expenditures (as per cent change from year ago, quarterly, seasonally adjusted annual rate) and trade openness is measured as the sum of exports (value goods, per cent of GDP, quarterly, seasonally adjusted) and imports (value goods, per cent of GDP, quarterly, seasonally adjusted). All these data come from the Saint-Louis Federal Reserve (Fred) online database. We checked for the presence of unit root, and both the ADF and PP tests with constant and trend reject the null of unit root, except for M2 where the PP test fails to reject the null. Nevertheless, we proceed without taking any difference on the ground that the ADF test rejects the null. We have run a lot of regressions, including controlling for one variable at the time and all control variables together. All the results show a significant negative relationship between unexpected inflation and output growth. For brevity and to conserve space, we report only the results that include all the control variables in Table VII. As one can see, both the OLS and GMM regressions confirm the previous results with the difference that the coefficients of our main variables in Table VII are larger compared to those in Table III. The R^2 has not significantly increased, however.

8. Conclusion

In this paper, we study the effect of unanticipated inflation on output when wages are indexed for the loss of purchasing power. First, we develop a theoretical model of the production process to show that when firms face a rigid demand and wholly index wages for the loss of purchasing power, unanticipated inflation causes the output to fall. Unanticipated inflation induces firms to reduce output by generating unexpected labor costs.

Then we test the proposed theoretical model using recent US data. For the entire period that is considered, we find evidence in support of our theoretical model. That is, unanticipated inflation reduces output growth. This finding contradicts a well-established belief that unanticipated inflation can be used to stimulate output.

Moreover, we consider the effect of the recent financial crisis on the relationship between unanticipated inflation and output, and we find that the relationship remains negative; however, it becomes quantitatively and qualitatively weaker after the crisis. This finding could be explained by the fact that firms are unable to reduce output by firing workers because of binding labor contracts and labor unions in some industries.

Method / Dependent variable	(1) OLS Growth rate of GDP	(2) GMM Growth rate of GDP	(3) OLS Growth rate of GDP	(4) GMM Growth rate of GDP
Independent variable				
$(1+COS_{t-4})w_{t-4}$	−0.052*** (0.013)	−0.095*** (0.027)		
$(1+Mich_{t-4})w_{t-4}$			−0.070*** (0.018)	−0.114*** (0.015)
$(\pi_t - COS_{t-4})w_{t-4}$	−0.023*** (0.006)	−0.039*** (0.012)		
$(\pi_t - Mich_{t-4})w_{t-4}$			−0.022*** (0.006)	−0.035*** (0.006)
M2	−0.011 (0.032)	−0.024 (0.042)	0.005 (0.030)	0.014 (0.029)
Investment	0.160*** (0.026)	0.269*** (0.065)	0.159*** (0.025)	0.209*** (0.034)
Government	−0.001 (0.037)	0.042 (0.070)	0.005 (0.033)	0.024 (0.040)
Trade	0.104* (0.059)	0.244** (0.111)	0.176** (0.076)	0.329*** (0.072)
$(Growth\ rate\ of\ GDP)_{t-1}$	0.434*** (0.072)	0.023 (0.187)	0.395*** (0.074)	0.166* (0.100)
Constant	2.026*** (0.638)	2.580** (1.036)	1.431** (0.592)	1.221 (0.782)
R^2	0.870		0.875	
Hansen's J *p*-value		0.432		0.661
Number of observations	137	137	140	138

Notes: Columns (1) and (2) use expected inflation based on consumer opinion survey, whereas Columns (3) and (4) use expected inflation based on the University of Michigan estimates. GMM estimates are based on a two-step GMM estimation with a weight matrix that is heteroskedasticity and autocorrelation (HAC) consistent. The lag order is automatically selected using Newey and West's (1994) optimal lag-selection algorithm. At the exception of the lag of the dependent variable, three lagged values of each independent variable plus the constant term are used as instruments. ***rejects at 1%; **rejects at 5%; *rejects at 10%; robust standard errors are in parentheses in Columns (1) and (3), HAC standard errors are in parentheses in Columns (2) and (4)

Table VII.
The empirical results (additional controls)

Our findings are useful for policymakers for several reasons. First, when a monetary authority is attempting to stimulate output by producing unexpected inflation, it should carefully consider its effect on the cost of labor through indexation. Second, a new monetary policy should be considered. If the objective of a monetary authority is to stimulate output, it should maintain higher expectations of inflation and then produce less inflation than is anticipated.

Notes

1. For a literature review refer to McCallum (1980).
2. We assume that the firm expects no productivity shocks. Therefore, nominal wages could only change because of inflation.
3. We use the unexpected cost caused by unexpected inflation estimate across the GMM results (–0.017) and the GMM results based on the University of Michigan expected inflation to get the estimate of the anticipated inflation in Column 4 (–0.021). We choose the University of Michigan expected inflation over that of the consumer opinion surveys given that the estimated coefficient of the expected inflation is not statistically significant as shown in Column 2.
4. We ran a robustness check using the first four lags for the independent variables as instruments, and the results are very similar to those based on the first three lags as instruments.

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Corresponding author

Ficawoyi Donou-Adonsou can be contacted at: fdonouadonsou@jcu.edu