Examining the Relationship Between Capacity Utilization and Inflation

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ABSTRACT

This paper provides insight into the complex relationship between capacity utilization and inflation in the U.S. economy. We test various current and expected inflation rates in separate models to examine the strength of relationship between capacity utilization and inflation from 1984-2018. We find the relationship between current inflation and capacity utilization has continued to weaken over time. Long run expected inflation and capacity utilization, however, have the strongest relationship, with changes in expected inflation having larger impact on utilization rates since 2000. These results suggest more emphasis should be placed on the relationship between capacity utilization and expected future inflation.

INTRODUCTION

Capacity utilization is often used as a metric to measure slack in the economy. It can be interpreted as the proportion of capacity being used from the total available capacity to produce finished goods. Capacity utilization tends to fluctuate with the business cycle. Firms adjust production up or down to respond to changes in demand. Average rates of capacity utilization in the United States have been falling since the 1970's. After historical highs of close to 90 percent capacity in the late 1960's and early 1970's, capacity utilization has been experiencing a decades-long downward trend. Utilization rates tend to fall sharply during a recession and are now rarely attaining pre-recession peaks (Pierce & Wisniewski, 2018).

Economic theory implies that high rates of capacity utilization put upward pressure on prices. With low rates of utilization, however, rising production does not require significant capital investment so firms can increase production with little to no impact on prices. Empirically, studies have shown that the correlation between total capacity utilization (TCU) and inflation has weakened since the early 1980's. Few studies have analyzed this relationship since 2000. If a relationship does still exist, or exists only at certain times (when capacity utilization is high or during technology shocks, for example), it is important for policy makers understand this relationship and its implications for the economy.

This study analyzes the relationship between capacity utilization and inflation from the Great Moderation through the financial crisis, the subsequent recession and the extended period of economic recovery since then. We extend the literature by including recent economic data through the end of 2018 to gather insight on how the relationship may have changed in recent years. Since TCU has not averaged utilization rates anywhere near the all-time highs of the 1960's and early 1970's and has not even come close to averages seen during the 1980's and early 1990's, we are not only concerned with upward pressure

that higher rates of TCU can put on prices, we are also interested if low utilization rates can be attributed to the stable prices that we have seen in recent years.

We test our models using three different measurements of current inflation and two measures of expected inflation. Specifically, we estimate two models using OLS regressions from 1984-2018 to estimate both inflation and total capacity utilization. We include four lags for the dependent and independent variables in each model. We alternate the dependent and independent variables in our models so we not only can determine the impact that TCU has on current and expected inflation rates, but also if the various inflation measures impact TCU. We include lags of the variables because information about current rates are not available in the current month due to the measurement of the data. Due to this, production decisions are made using available information which would most likely is between 1-4 months prior. Additionally, if firms increase production and subsequently capacity utilization rates rise, it is reasonable to assume that it could take several months for prices to respond. Conversely, if firms adjust production based on not only the prices they are experiencing in current month, but also on information regarding prices from previous months, then we would see previous inflation rates affecting TCU in our model. Therefore, including lags to capture previous months' information in our models is important.

The Great Moderation is most often assumed to have begun in the first quarter of 1984. Since that time, the U.S. as well as the global industrialized economies have seen decreased volatility in aggregate variables, most notably GDP growth rates. This time of low volatility is often attributed to improved monetary policies and better inventory management techniques (Summers, 2005). This study analyzes the relationship between the two variables over this time period to determine if capacity utilization continues have a weak relationship with inflation rates as theory would predict. We extend the sample period into the new millennia and include the financial crisis, recession and recovery period to capture the relationship between the variables in recent years. Additionally, we re-estimate both models using two subsets of the sample period. The first subset is from 1984-1999 and the second is 2000-2018, reflecting the years since the Federal Reserve switched its inflation target from the Consumer Price Index (CPI) to core Personal Consumption Expenditures (Core PCE) in 2000.

As we focus on all aspects of inflation, we will be able to determine which price indexes have a stronger with TCU. Additionally, we incorporate two expected inflation indexes, to compare the relationship between TCU to both short-term and long-term expected inflation. There is little existing literature that test the relationship between survey inflation expectations and industry capacity utilization. This study seeks to fill that gap by comparing the relationship between capacity utilization to both short-term and long-term expected inflation to determine the role of expectations in production decisions as well as any impact of changes in TCU on inflation expectations. If the results show that the relationship varies between TCU and the various price indices, this could have further implications on the conduct of monetary policy.

We find there is a weak relationship between TCU and inflation. The relationship also appears to have changed in recent years. Of the current inflation indexes, core PCE has the weakest relationship with capacity utilization. Core PCE does not respond to changes in TCU. The second lag of core PCE has a

negative effect on TCU in the full model as well as from 1984-1999. This result changes after 2000, however. In the second subperiod, core PCE is the only current inflation measure to have any effect on TCU. This change in response since 2000 could be indicative of the Fed's decision to use core PCE as its inflation indicator. Firms may now use changes in this index as indicators of changes in inflation and adjust production accordingly. The impact is fairly small however. When core PCE increases by one percent, TCU increases by 0.03 percent two months afterwards.

When using CPI as the measure of current inflation, we see that the effect of changes in TCU on CPI has gotten stronger since 2000, but TCU does not respond to changes in inflation measured by CPI. The producer price index (PPI) is the only inflation measure that is impacted by changes in TCU in the full sample period as well in as the two sub-periods. The second lag of TCU is statistically significant in all periods and implies that a one percent increase in capacity utilization rates roughly increases PPI inflation by 3-5 percent. Furthermore, this impact appears to have gotten stronger since 2000. This implies that it takes two months for prices to respond to changes in capacity utilization rates.

Our results show that changes in long-term expected inflation rates have the largest impact on capacity utilization. The effect has gotten stronger in recent years as capacity utilization rates have been on a declining trend. Additionally, we find a bidirectional relationship between TCU and long-term expected inflation but the impact of TCU on expected inflation has weakened in recent years. These results imply that the Fed may want to put more emphasis on the relationship between long term expected inflation and capacity utilization when making decisions about the future conduct of monetary policy.

CAPACITY UTILIZATION

The Federal Reserve Board releases monthly measurements of capacity utilization rates. The capacity indexes are constructed for 89 industries and consist of various groups including total manufacturing as well as durable and nondurable manufacturing. Total capacity utilization (TCU) is the (seasonally adjusted) output index divided by the capacity index for the total industry. This variable measures the amount of capacity being utilized in comparison to total available capacity for goods produced in mining, manufacturing, electric, and gas utilities. Capacity utilization rates attempt to measure maximum sustainable output in the economy. This is the level of output that can be maintained given realistic work schedules, down time and availability of inputs in production. The proportion of potential economic output actually realized can give insight into overall slack in the economy. The total capacity utilization rate can also indicate the amount firms are able to produce without an increase in costs and the amount of future demand a firm will be able to satisfy.

The Census Bureau and Federal Reserve have their own methods for measuring capacity utilization. The Census Bureau bases its estimates on a subsample of a survey sent to about 450 manufacturing plants to calculate preferred and practical capacity utilization indexes. The Federal Reserve relies on surveys conducted by McGraw-Hill and the Census Bureau to calculate monthly capacity utilization rates. The two series tend to move together, but are constructed using vastly different methods.

Capacity utilization is useful for evaluating industry price pressures, investment, and war mobilization capabilities (Bauer & Deily, 1988). Bauer and Deily give detailed explanations of the Federal Reserve's and the Census Bureau's measures of capacity utilization. Estimates from the Census Bureau represent manufacturing, which account for just 20-22 percent of GDP and only covers the fourth quarter of each year. There is a question of the quality of the data because it is unclear who responds to the surveys and how the questions are interpreted. The Federal Reserve approach uses a relatively small sample and consistency is hard to achieve. Both series tend to have limitations but Bauer and Deily conclude the Federal Reserve's approach may be the most reasonable way of measuring capacity utilization.

CAPACITY UTILIZATION AND INFLATION

The relationship between inflation and capacity utilization is complex. According to Keynesian theory, when capacity utilization rates are high, there is a strong relationship between capacity utilization and inflation but when capacity utilization rates are lower, the relationship weakens. According to the theory, when capacity utilization is low, firms can increase their employment and capital usage without having to simultaneously increase prices cover the increases in production costs. Firms, therefore, are able to increase output with little to no impact on inflation. When utilization rates are high, however, firms incur higher production costs in order to increase output. Firms raise prices to offset increases in production costs, ultimately leading to higher inflation.

Inflation rates may also rise during a technology shock (Finn, 1996). When an economy is experiencing a technology shock, productivity tends to increase. Dotsey and Stark (2005) find the link between capacity utilization and inflation is not consistent over time, however. They plot core PCE Inflation, and capacity utilization for the years 1959 to 2003. The raw data do not give a clear indication of the relationship as the variables move together in some periods and at other times move oppositely implying there may be times where the relationship is stronger than others.

Bauer (1990) and Corrado and Mattey (1997) discuss the impact marginal cost may have on the relationship. Bauer provides an alternative view of defining capacity as the level of output at which average cost is minimized. At points where output is below capacity, the marginal cost of increasing output is relatively small. When output is above capacity, the marginal costs increase more rapidly with increases in output.

Nakibullah and Shebeb (2013) put emphasis on a cost-input analysis and a dual cost measure to find capacity utilization. Their findings support the Keynesian theory that the relationship between the two variables is strongest when capacity utilization is high.

Corrado and Mattey test the correlation between capacity utilization and future inflation over the business cycle. They find capacity utilization is directly correlated with future inflation. Conversely, they find the correlation between capacity utilization and the Consumer Price Index from 1967-1995 is virtually zero. When they exclude food and energy prices, the correlation between capacity utilization and inflation is relatively strong, however. They find capacity utilization is an important indicator of inflation which works as

well or better than other possible inflation indicator variables at the one to two-year horizons and has the advantage of being more stable over time.

Ahmed and Cassou (2017) also support the findings of Corrado and Mattey. They test the relationship between TCU and inflation and find there are short run and long run connections. They question whether TCU can predict future inflation, however. Specifically, results from regression analysis show a change in the inflation rate leads to a change in capacity utilization. This conclusion differs from most findings as inflation is typically viewed as the dependent variable.

As this is a complex relationship, Gittings (1989) conducts a sector-by-sector analysis by focusing on the impact of cost and price changes in the economy. When focusing on separate industries, Gittings finds only a few industries have sufficient price and capacity time series. This implies caution should be used when assuming the relationship between capacity utilization and inflation is the same throughout the economy.

Garner (1994) examines whether capacity utilization can be used as a reliable indicator of inflationary pressures. He specifically focuses on capacity utilization in the manufacturing sector and focuses on a thirty-year period from 1964-1993 and estimates inflation using CPI. Garner uses OLS regression to estimate a stable-inflation rate of capacity utilization by using inflation as the dependent variable. He finds similar results to previous studies and concludes that the stable-inflation rate of capacity utilization has remained steady at around 82 percent and finds no evidence that the relationship has weakened amidst rapid technology growth or strong business investment.

Finn (1996) observes that inflation and capacity utilization move together at times, but also at other times move in opposite directions. Most often when the variables move in opposing directions the movements are small. Two notable exceptions were during the energy price crises in 1973-1974 and again in 1979. Finn develops a new neoclassical theory showing that because of the inflation tax, exogenous changes in money growth cause decreases in utilization rates while causing increases in inflation. Other aspects of money neutrality, like sticky prices may be the reason for the positive relationship between inflation and utilization. When the money growth response is strong, inflation will increase along with capacity utilization.

Emery and Chang (1997) test not only the impact of TCU on inflation but the relationship between the two variables. They find that since 1983 the relationship has deteriorated when using CPI as the inflation measure. The PPI has slightly more predictive power on TCU particularly when analyzing quarterly or semiannually horizons. Ceccetti (1995) finds evidence that capacity utilization adds significant explanatory power to out of sample forecasts of inflation prior to 1982 but not in years afterwards.

In 1997, The Board of Governors of the Federal Reserve System completed a revision of its measures of output, capacity utilization for the industrial sector revising estimates back to 1977. The revision primarily comprised of using weights that are updated annually as opposed to every five years (Corrado, Gilber, Raddock, & Kudon, 1997). This resulted in a downward revision of estimates for total capacity utilization. This could explain some of the conflicting results found in studies conducted prior to this time.

IMPLICATIONS FOR MONETARY POLICY

The link between inflation and TCU has implications for monetary policy. Dotsey and Stark find the Fed's decision to pursue an accommodative policy will have different consequences for inflation depending on the current level of capacity utilization. For instance, the economy may see less inflation when capacity utilization is low with accommodative policy. As prices rise, output levels will normalize over the long run. At normal rates of utilization, they find a negative relationship between the two variables.

The Fed seeks to maintain stable prices and achieve maximum employment as mandated by the by Congress under the Federal Reserve Act of 1977. Therefore, the Fed's ability to correctly model inflation and make accurate predictions is important for the conduct of monetary policy as well as future expectations of prices in the U.S. economy. The Federal Reserve recognizes TCU as an important economic indicator and economists have acknowledged the predictive power of total capacity utilization on inflation since the 1970's. Understanding the relationship between TCU and inflation is therefore important in making accurate monetary policy decisions. Dotsey and Stark show the strength of the relationship has begun to deteriorate since the 1980's. This can be partly attributed to the changing nature of monetary policy. The accuracy of the Fed's predictions of the current and future state of the economy is important for investment decisions and these decisions ultimately impact financial markets.

DATA

We use monthly data from 1984 through 2018 and test the relationship between total capacity utilization and inflation over the entire sample period as well as two sub-periods. 1984 is roughly the beginning of the period commonly known as the Great Moderation, where inflation began to stabilize after the volatility of inflation rates seen in the 1970's. This period of relative macroeconomic stability lasted until the financial crisis in 2007-2008. Since the financial crisis, both capacity utilization and inflation rates have remained relatively low, with the exception of PPI which has seen extreme volatility, particularly since the Great Recession. We chose to split the period into the sub-periods of 1984-1999 and 2000-2018 because the Fed changed its inflation target from CPI to core PCE in 2000. This will allow us to see if the relationship between TCU and inflation has changed based on the inflation indicators used by the Fed during each time period.

We estimate our models in repeated OLS regressions using alternative measures of inflation. Actual inflation is unobservable and therefore cannot be directly measured. There are several variables to estimate the level of inflation, however. Specifically, we use three prices indexes to estimate inflation rates: Consumer Price Index (CPI), Producer Price Index (PPI), Personal Consumption Expenditures less food and energy prices (Core PCE)[1]. CPI and PPI are obtained from the U.S. Bureau of Labor Statistics and the U.S. Bureau of Economic Analysis is the source for Core PCE.

Analyzing the differences in the relationship between seasonally adjusted total industry capacity utilization (TCU), obtained from the Federal Reserve Board of Governors, and the three measures of inflation

is important because each price index encompass a different aspect of the economy. CPI measures the weighted average of a market basket of goods and services purchased by a typical family of four, which includes imported goods. Core PCE measures the amount consumers in the U.S. spend on goods and services, minus food and energy prices which reduces the volatility in the index. PPI measures the average selling price of goods and services produced in the U.S. It measures sales of goods at all stages of production. Since PPI incorporates both the prices firms receive for finished goods and what they pay for intermediate goods, total capacity utilization and inflation may be more closely related based on this inflationary measure. Changes in PPI can reflect temporary supply and demand imbalances so using PPI for long-term forecasting can be difficult.

Table 1: Descriptive Statistics

Panel A: 1984-2017

	Months	Mean	Std. Dev.	Min	Max
CPI	420	2.69	1.33	-1.96	6.38
PPI	420	2.10	4.56	-16.06	17.36
Core PCE	420	2.29	0.97	0.90	4.71
MICH	420	3.04	0.56	0.40	5.20
CLEVE30	420	2.87	0.63	1.91	4.77
TCU	420	79.29	3.57	66.69	85.15

Panel B: 1984-1999

	Months	Mean	Std. Dev.	Min	Max
CPI	192	3.27	1.15	1.19	6.38
PPI	192	1.38	2.52	-3.76	7.09
Core PCE	192	2.96	1.05	0.98	4.71
MICH	192	3.14	0.50	2.30	4.80
CLEVE30	192	3.42	0.44	2.60	4.77
TCU	192	81.96	1.89	78.06	85.15

Panel C: 2000-2017

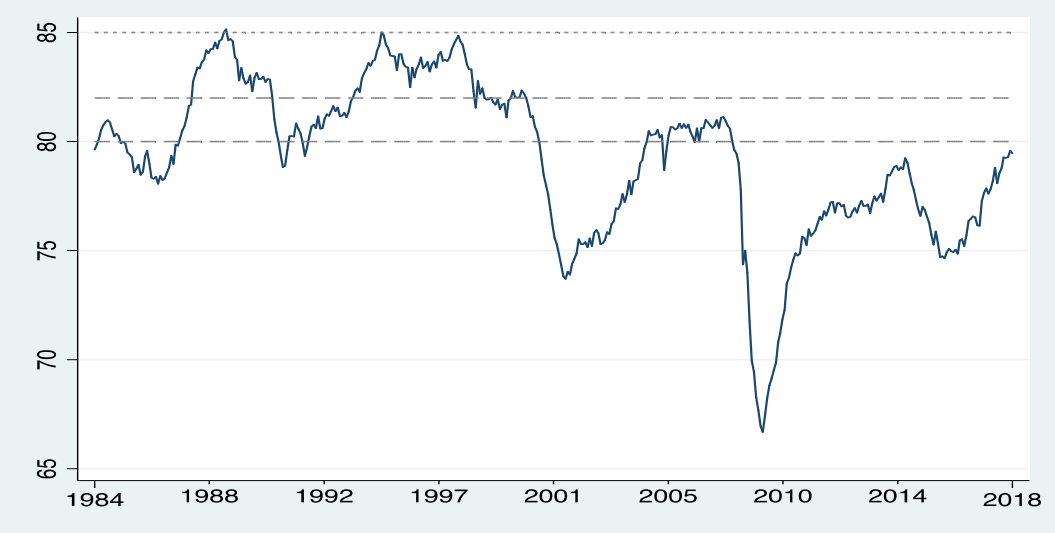
	Months	Mean	Std. Dev.	Min	Max
CPI	228	2.19	1.27	-1.96	5.50
PPI	228	2.70	5.68	-16.06	17.36
Core PCE	228	1.73	0.36	0.90	2.55
MICH	228	2.96	0.59	0.40	5.20
CLEVE30	228	2.40	0.30	1.91	3.22
TCU	228	77.05	3.08	66.69	82.34

Notes and Sources: Federal Reserve's Board of Governors, Bureau of Labor Statistics, Bureau of Economic Analysis, University of Michigan, Federal Reserve Bank of Cleveland. Inflation variables are author calculations for annual percentage change in the price level.

Both Gittings (1989) and Bauer (1990) determine a "natural rate" of capacity utilization and find it to be between 80 percent and 82 percent. Finn (1995) notes that capacity utilization rates above 85 percent create bottlenecks where supply and labor are short and soon after, key price indexes begin to surge. This helps determine how the relationship can change due to high or low levels of capacity utilization. Figure 1 is a graph of TCU from 19984-2018. The short-dashed line represents the threshold for what Finn estimates as "high" utilization rates. Historically, we have not seen rates consistently above 85 percent since the 1970's. In fact, there has only been one month that TCU has been at or above 85 percent since 1979. That was in January 1989, when TCU peaked at 85.15 percent. The long-dashed lines represent the natural rate between 80-82 percent of capacity usage. From 1984-1999, capacity utilization was above the natural rate approximately 38 percent of the time, however, having 73 months where TCU was above 82 percent. Additionally, 43 percent of the time, TCU was at both Bauer and Gittings' estimates for the natural rate.

We not only test the relationship between capacity utilization and various actual inflation rates, we are also interested in learning how expectations impact capacity utilization. Therefore, we test whether changes in capacity utilization affect both short-term and long-term expected inflation rates as well as whether expected inflation affects capacity utilization rates. We use the Survey of Consumers conducted by the University of Michigan (MICH) to measure short-term expected inflation. In addition, we use the Cleveland Federal Reserve Bank's model, which estimates the 30-year average annual expected inflation rate (CLEVE30). These rates are what inflation is expected to average over the next 30 years.[2]

Figure 1. Total Capacity Utilization Rates, 1984-2018.



Source and Notes: Federal Reserve Board of Governors. Dashed lines indicate "natural rate" of capacity utilization. Short dashed line indicates "high" utilization threshold zone.

Table 1 presents descriptive statistics for the data. Panel A represents the entire sample period, while Panels B and C present statistics for the sub-periods of 1984-1999 and 2000-2018 respectively. As

seen from Panel B, rates of capacity utilization from 1984-1999 are significantly higher than the rates in the latter period of 2000-2018. Additionally, differences can be seen between inflation and expected inflation measures. Both expected inflation rates for 1984-1999 are above 3 percent, but after 2000 are below 3 percent with 30-year expected inflation averaging 2.4 percent.

Conversely, at no point from 2000-2018 was TCU above the natural rate and only at the natural rate roughly 15 percent of the time (34 out of 228 months). We can also see more volatility in TCU after 2000. This can be attributed to the Great Recession that followed the financial crisis where capacity utilization dipped below 70 percent in 2009 falling as to 66.7 percent in June 2009.

METHODOLOGY

We are primarily interested in determining whether the relationship between TCU and inflation has changed over time. To test this, we specify two models by alternating the dependent and independent variables. We estimate an OLS regression using four lagged variables of the dependent and independent variables. Specifically, the model to determine the impact of TCU on inflation is:

$$\pi_t = \alpha_0 + \alpha_1\pi_{t-1} + \alpha_2\pi_{t-2} + \alpha_3\pi_{t-3} + \alpha_4\pi_{t-4} + \alpha_5\mathrm{TCU}_t + \alpha_6\mathrm{TCU}_{t-1} + \alpha_7\mathrm{TCU}_{t-2} + \alpha_8\mathrm{TCU}_{t-3} + \alpha_9\mathrm{TCU}_{t-4} + \varepsilon_t \quad (1)$$

where π is the inflation rate as measured by the annual percentage change in the price index for month *t*. TCU is the total capacity utilization rate in month *t*. Equation (1) will determine if changes in current as well as previous months' capacity utilization rates influence changes in inflation in each period.

Next, we re-estimate the model alternating the dependent and independent variables to test to impact of changes in inflation on capacity utilization. This method is similar to Ahmed and Cassou who use capacity utilization as the dependent variable in their model. This will allow us not only to determine the impact of capacity utilization on inflation, but will help determine the overall relationship between the two variables. With TCU as the dependent variable, the model now becomes:

$$TCU_t = \beta_0 + \beta_1 TCU_{t-1} + \beta_2 TCU_{t-2} + \beta_3 TCU_{t-3} + \beta_4 TCU_{t-4} + \beta_5\pi_t + \beta_6\pi_{t-1} + \beta_7\pi_{t-2} + \beta_8\pi_{t-3} + \beta_9\pi_{t-4} + \varepsilon_t \quad (2)$$

We estimate Equation (1) and (2) for the entire sample period. We then re-estimate both models for the sub-periods,1984-1999 and 2000-2018. All inflation indexes are incorporated as inflation rates of percent change from a year ago and all variables are in first differences to correct for unit roots. We estimate both equations for each of the three price indexes and two measures of expected inflation.

EMPIRICAL RESULTS

Simple correlations between TCU and the various inflation measures are presented in Table 2. The correlations between TCU and all of the measures of current and expected inflation are not consistent over time. Similar to the findings of Corrado and Mattey, we find the correlation between CPI and TCU from 1984-1999 to be close to zero. Over the entire sample period and more specifically since 2000, however, the correlation is much greater. Core PCE is negatively correlated with TCU prior to 2000 but has a positive correlation of 0.644. Similarly, 30yr expected inflation rates is negatively correlated in the first sub-period and only weakly correlated from 2000-2018. PPI appears to have the most stable relationship over time but does not display a strong correlation over the entire sample period.

Table 2: Correlation between Total Capacity Utilization and Inflation and Expected Inflation Rates

	CPI	PPI	Core PCE	MICH	CLEVE30
1984-2018	0.561	0.271	0.462	0.325	0.584
1984-1999	0.020	0.464	-0.310	0.140	-0.313
2000-2018	0.624	0.529	0.644	0.378	0.376

Note: Inflation variables are author calculations for annualized percentage change in the price level.

Regression results for Equation (1) are presented in Table 3 for the entire sample period, where the different measures of inflation are the dependent variable and TCU is the independent variable. For this model, the variables of interest are the coefficients for current and lagged TCU. These results show the empirical relationship between capacity utilization and inflation. Neither the CPI nor Core PCE are affected by changes in current or lagged TCU rates. The only measure of current inflation that is impacted by changes in TCU is PPI. As seen from Column 2 of Table 3, a one percent increase in TCU would cause a 3.49 percent increase in the PPI inflation rate. These results are not surprising given that PPI is the most volatile of the three inflation indicators and most sensitive of changes in production costs. Changes in the utilization rate do not affect short-term inflation expectations (MICH). Long-term expected inflation measured by CLEVE30 is used as the regressor, we find TCU is statistically significant at the current value of TCU, and first and the fourth lags. This implies that long-term inflation expectations are affected by changes in TCU for the current month, but also when TCU has changed in the previous month and as far back as four months, possibly indicating that inflation expectations are impacted by changes that occur in the previous quarter.

We would expect some or all of the lagged inflation variables to be significant in all models. As previous inflation rates can be highly predictive for estimating future inflation rates. The results for the estimated coefficients for the current inflation variables are not consistent, however. CPI is influenced by the previous month's inflation rate and negatively affected by the second lag of inflation. PPI is only significant at the first lag and the effect is smaller than for CPI. Core PCE, on the other hand, is not influenced by the previous month's inflation rates, but months 2-4 are statistically significant. Short term expected inflation

(MICH) has negative coefficients and are statistically significant for one and four-month lags. The effect on long-term expected inflation is negative for the second lag and positive but relatively small (0.02) for the fourth lag.

Table 3: Regression Results: Equation (1) 1984-2018

Coefficients	CPI	PPI	Core PCE	MICH	CLEVE30
π_{t-1}	0.513***	0.327***	0.128	-0.113*	0.042
	(0.082)	(0.081)	(0.109)	(0.068)	(0.052)
π_{t-2}	-0.183***	0.047	0.084**	-0.109	-0.098*
	(0.070)	(0.076)	(0.042)	(0.081)	(0.055)
π_{t-3}	0.019	-0.017	0.239***	-0.060	0.034
	(0.068)	(0.087)	(0.050)	(0.053)	(0.054)
π_{t-4}	0.027	-0.027	0.225***	-0.148***	0.025***
	(0.069)	(0.069)	(0.059)	(0.049)	(0.009)
TCU_t	-0.435	0.173	0.165	0.013	0.029***
	(0.428)	(1.789)	(0.122)	(0.047)	(0.008)
TCU_{t-1}	0.261	2.038	0.143	0.004	0.015*
	(0.565)	(2.257)	(0.165)	(0.038)	(0.008)
TCU_{t-2}	0.970	3.492**	0.008	0.081	-0.005
	(0.634)	(1.739)	(0.133)	(0.051)	(0.009)
TCU_{t-3}	0.332	1.950	0.006	0.075	-0.002
	(0.338)	(1.293)	(0.146)	(0.053)	(0.011)
TCU_{t-4}	-0.200	-0.946	-0.176	0.001	-0.025***
	(0.290)	(1.289)	(0.128)	(0.037)	(0.009)
Constant	1.610***	1.279***	0.702***	-0.003	-0.005
	(0.240)	(0.462)	(0.166)	(0.015)	(0.004)
Observations	416	416	416	416	416
R-squared	0.245	0.195	0.256	0.059	0.055

Notes: π represents the inflation variable for each column. Robust standard errors in parentheses.

*, **, *** denote statistical significance at 90%, 95 % and 99 % confidence levels respectively.

Table 3 represents the regressions for the entire period. To analyze how the relationship may have changed over time, we split the sample into the two sub-periods. Breaking down the data into two time periods gives further insight into how the relationship has changed since the 1980's. Table 4 shows estimates of Equation (1) for the years 1984-1999. Similar to the results for the full sample period, CPI and Core PCE and MICH do not respond to changes in utilization rates. PPI, however, is still highly responsive to changes in the previous month's capacity utilization. The impact of changes in TCU, TCU_{t-1}, and TCU_{t-4} on CLEV30 are slightly larger in the first sub-period as compared to the overall sample.

Table 4: Regression Results: Equation (1) 1984-1999

Coefficients	CPI	PPI	Core PCE	MICH	CLEVE30
π_{t-1}	0.411***	0.462***	0.227***	-0.256***	0.011
	(0.097)	(0.111)	(0.078)	(0.094)	(0.076)
π_{t-2}	-0.044	-0.174*	0.047	-0.014	-0.065
	(0.096)	(0.091)	(0.068)	(0.080)	(0.079)
π_{t-3}	0.157*	0.104	0.284***	-0.255***	0.019
	(0.091)	(0.105)	(0.074)	(0.077)	(0.075)
π_{t-4}	-0.061	-0.048	0.145**	-0.156**	0.034***
	(0.071)	(0.116)	(0.068)	(0.073)	(0.009)
TCU_t	0.232	-0.100	0.383	0.000	0.034**
	(0.415)	(1.346)	(0.248)	(0.047)	(0.015)
TCU_{t-1}	0.512	3.003***	0.047	0.020	0.053***
	(0.393)	(1.139)	(0.262)	(0.046)	(0.017)
TCU_{t-2}	-0.140	0.635	0.004	0.082*	0.016
	(0.360)	(1.139)	(0.236)	(0.047)	(0.019)
TCU_{t-3}	-0.388	0.575	-0.074	0.042	-0.011
	(0.377)	(1.270)	(0.262)	(0.051)	(0.019)
TCU_{t-4}	0.055	-0.631	-0.198	0.049	-0.052**
	(0.355)	(1.036)	(0.228)	(0.043)	(0.020)
Constant	1.672***	0.824**	0.796***	-0.009	-0.008
	(0.383)	(0.383)	(0.253)	(0.020)	(0.006)
Observations	188	188	188	188	188
R-squared	0.199	0.228	0.304	0.136	0.112

Notes: π represents the inflation variable for each column. Robust standard errors in parentheses.
*, **, *** denote statistical significance at 90%, 95% and 99% confidence levels respectively.

The estimates for the regressions for the period beginning in 2000 are given in Table 5. The estimated coefficients for TCU on the three inflation variables are quite different than in the prior period. In the overall sample and from 1984-1999, CPI does not respond to changes in TCU. Since 2000, however, a 1 percent change in TCU_{t-2} indicates a 1.57 percent change in inflation as measured by CPI. It also has a larger impact on PPI with an estimated coefficient of 4.872. When Core PCE is used as the dependent variable for estimating inflation, almost all of the coefficients become insignificant. More importantly, the R^2 falls to 0.05 due to the high variability of the inflation variable around the fitted values. The impact of utilization on long term inflation expectations also weakens during this time period. Only current TCU remains significant although the relative size of the coefficient remains consistent.

Table 5. Regression Results: Equation (1) 2000-2018

Coefficients	CPI	PPI	Core PCE	MICH	CLEVE30
π_{t-1}	0.519***	0.306***	-0.086	0.024	0.047
	(0.097)	(0.093)	(0.181)	(0.083)	(0.073)
π_{t-2}	-0.207**	0.084	-0.052	-0.210*	-0.172**
	(0.081)	(0.085)	(0.073)	(0.108)	(0.078)
π_{t-3}	-0.033	-0.039	0.051	0.084	0.081
	(0.089)	(0.099)	(0.061)	(0.065)	(0.069)
π_{t-4}	0.016	-0.040	0.131**	-0.219***	-0.037
	(0.089)	(0.081)	(0.064)	(0.066)	(0.068)
TCU_t	-0.608	0.423	0.045	0.012	0.030***
	(0.660)	(2.828)	(0.141)	(0.066)	(0.010)
TCU_{t-1}	0.166	1.336	0.258	-0.012	-0.005
	(0.827)	(3.578)	(0.199)	(0.055)	(0.010)
TCU_{t-2}	1.570*	4.872*	0.068	0.095	-0.011
	(0.886)	(2.495)	(0.178)	(0.073)	(0.011)
TCU_{t-3}	0.531	2.715	0.074	0.091	0.001
	(0.477)	(1.881)	(0.171)	(0.074)	(0.014)
TCU_{t-4}	-0.443	-1.424	-0.064	-0.023	-0.008
	(0.417)	(1.962)	(0.163)	(0.051)	(0.009)
Constant	1.498***	1.675**	1.645***	-0.000	-0.004
	(0.283)	(0.771)	(0.348)	(0.022)	(0.004)
Observations	224	224	224	224	224
R-squared	0.286	0.205	0.050	0.116	0.077

Notes: π represents the inflation variable for each column. Robust standard errors in parentheses.
*, **, *** denote statistical significance at 90%, 95% and 99% confidence levels respectively.

Results for Equation (2) are presented in Tables 6 through 8, where the TCU is the dependent variable and the inflation indexes are the independent variable in each column. The results in Table 6 encompass the entire time period, while Table 7 includes the regression results from 1984-1999 and Table 8 displays results from 2000-2017. With these sets of results, we are now interested in the inflation coefficients. As seen in the results presented in Table 6, the current inflation measures do not affect the rates of capacity utilization. This implies a weak relationship between the variables. When comparing TCU and expected inflation rates, the relationship is stronger for 30-year expected inflation. The results for the entire sample period are similar to those found in Table 7 for 1984-1999. The second lags of inflation measured by CPI and Core PCE are both negative and significant at the 90% level of confidence but no other current inflation indicators are statistically significant from zero in this model. The effects of long-term expected inflation on TCU are smaller than for the full sample. Only coefficients for current and π_{t-1} are significant in this model.

Table 6: Regression Results: Equation (2) Years 1984-2018

Coefficients	CPI	PPI	Core PCE	MICH	CLEVE30
TCU_{t-1}	0.064	0.051	0.050	0.048	0.020
	(0.081)	(0.082)	(0.082)	(0.083)	(0.081)
TCU_{t-2}	0.159***	0.131**	0.150***	0.149***	0.138***
	(0.053)	(0.053)	(0.050)	(0.052)	(0.050)
TCU_{t-3}	0.206***	0.198***	0.221***	0.207***	0.217***
	(0.059)	(0.059)	(0.067)	(0.062)	(0.059)
TCU_{t-4}	0.143***	0.141***	0.159***	0.142***	0.185***
	(0.050)	(0.050)	(0.056)	(0.051)	(0.056)
π	-0.012	0.000	0.020	0.025	0.889***
	(0.011)	(0.003)	(0.015)	(0.092)	(0.268)
π_{t-1}	0.026*	0.007	0.019	0.170**	0.523*
	(0.014)	(0.004)	(0.016)	(0.076)	(0.268)
π_{t-2}	-0.009	-0.001	-0.009	0.070	0.450*
	(0.013)	(0.004)	(0.016)	(0.065)	(0.247)
π_{t-3}	0.004	0.001	-0.007	0.029	0.044
	(0.011)	(0.003)	(0.015)	(0.080)	(0.254)
π_{t-4}	-0.004	-0.002	-0.019	-0.012	-0.103*
	(0.007)	(0.003)	(0.016)	(0.071)	(0.054)
Constant	-0.017	-0.013	-0.010	-0.002	0.007
	(0.045)	(0.020)	(0.049)	(0.021)	(0.021)
Observations	416	416	416	416	416
R-squared	0.167	0.176	0.156	0.163	0.185

Notes: π represents the inflation variable for each column. Robust standard errors in parentheses.
*, **, *** denote statistical significance at 90%, 95% and 99% confidence levels respectively.

Table 7: Regression Results: Equation (2) 1984-1999

Coefficients	CPI	PPI	Core PCE	MICH	CLEVE30
TCU_{t-1}	-0.048	-0.048	-0.036	-0.048	-0.095
	(0.084)	(0.084)	(0.088)	(0.090)	(0.097)
TCU_{t-2}	0.130	0.120	0.161**	0.148*	0.085
	(0.083)	(0.083)	(0.077)	(0.084)	(0.087)
TCU_{t-3}	0.214***	0.209**	0.190**	0.204**	0.182**
	(0.076)	(0.081)	(0.078)	(0.081)	(0.079)
TCU_{t-4}	0.045	0.058	0.021	0.031	0.059
	(0.062)	(0.064)	(0.067)	(0.062)	(0.074)
π	0.009	-0.000	0.036	0.001	0.682**
	(0.017)	(0.007)	(0.024)	(0.101)	(0.299)
π_{t-1}	0.027	0.009	0.030	0.163	0.716**
	(0.016)	(0.008)	(0.026)	(0.106)	(0.304)
π_{t-2}	-0.038**	-0.007	-0.056**	-0.030	0.099
	(0.016)	(0.006)	(0.024)	(0.121)	(0.332)
π_{t-3}	-0.013	-0.006	-0.015	-0.221	0.045
	(0.017)	(0.006)	(0.021)	(0.148)	(0.303)
π_{t-4}	-0.004	-0.004	0.002	-0.141	-0.021
	(0.015)	(0.005)	(0.023)	(0.117)	(0.039)
Constant	0.064	0.019	0.017	0.006	0.018
	(0.078)	(0.030)	(0.080)	(0.029)	(0.030)
Observations	188	188	188	188	188
R-squared	0.107	0.094	0.105	0.095	0.102

Notes: π represents the inflation variable for each column. Robust standard errors in parentheses.
*, **, *** denote statistical significance at 90%, 95% and 99% confidence levels respectively.

Evidence of the weakening relationship between current inflation and TCU in recent years is presented in Table 8. Core PCE is the only current inflation measure that is statistically significant when used as a regressor. The second lag of inflation for Core PCE is 0.037, indicating a 1 percent increase in inflation would result in a 0.037 percent increase in utilization. Although the coefficients for π_{t-2} are statistically significant at the 95 percent confidence level for both sub-periods, the coefficient is negative in the first period and positive in the latter time period. The relationship between CLEVE30 and TCU has gotten stronger over time. The estimated coefficients for current and the second lag of CLEVE30 are large and highly significant. This result implies that expectations of future inflation have a greater impact on production decisions that actual inflation rates.

Table 8. Regression Results: Equation (2) 2000-2018

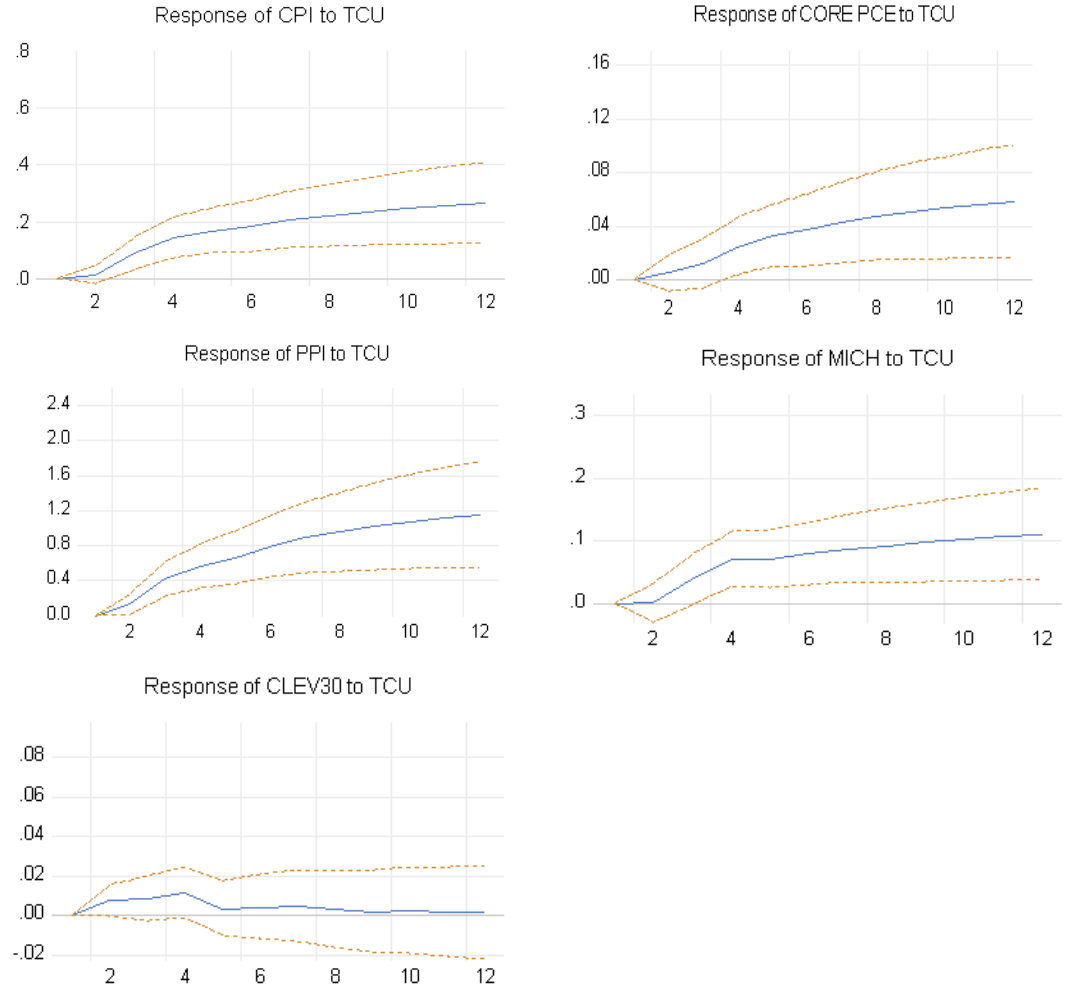
Coefficients	CPI	PPI	Core PCE	MICH	CLEVE30
TCU_{t-1}	0.095	0.086	0.091	0.076	0.069
	(0.127)	(0.125)	(0.126)	(0.125)	(0.125)
TCU_{t-2}	0.161**	0.114	0.145**	0.131**	0.133**
	(0.072)	(0.069)	(0.067)	(0.066)	(0.065)
TCU_{t-3}	0.207***	0.192**	0.211**	0.205***	0.217***
	(0.077)	(0.078)	(0.086)	(0.079)	(0.070)
TCU_{t-4}	0.191***	0.200***	0.215***	0.206***	0.248***
	(0.067)	(0.064)	(0.071)	(0.065)	(0.069)
π	-0.014	0.001	0.007	0.023	1.352***
	(0.016)	(0.004)	(0.023)	(0.129)	(0.474)
π_{t-1}	0.024	0.006	0.020	0.162	0.459
	(0.018)	(0.005)	(0.021)	(0.102)	(0.452)
π_{t-2}	-0.001	-0.001	0.037**	0.108	1.260***
	(0.017)	(0.004)	(0.018)	(0.074)	(0.420)
π_{t-3}	0.006	0.003	-0.000	0.142	0.271
	(0.014)	(0.003)	(0.026)	(0.096)	(0.465)
π_{t-4}	-0.003	-0.002	-0.028	0.025	-0.255
	(0.009)	(0.003)	(0.024)	(0.097)	(0.655)
Constant	-0.030	-0.021	-0.065	-0.005	0.007
	(0.050)	(0.028)	(0.101)	(0.030)	(0.032)
Observations	224	224	224	224	224
R-squared	0.244	0.255	0.234	0.243	0.281

Notes: π represents the inflation variable for each column. Robust standard errors in parentheses.
*, **, *** denote statistical significance at 90%, 95% and 99% confidence levels respectively.

It should be noted that the R^2 for the regression are low, especially for time-series analyses. But as we primarily interested in the relationship between the two variables and not trying to predict the dependent variables in the regressions, the size and significance of the estimated coefficients provide information about the response of the dependent variables even though the low R^2 implies high variability around the data.

As alternative specifications, we use manufactured goods, as well as durable and non-durable goods in place of TCU in both models. This would allow us to test the if the relationships were dependent upon industry sector. All series are monthly observations obtained from the Federal Reserve's Board of Governors and are transformed into first differences. Results for all three alternative models produced similar results as the models using TCU and therefore are not reported.

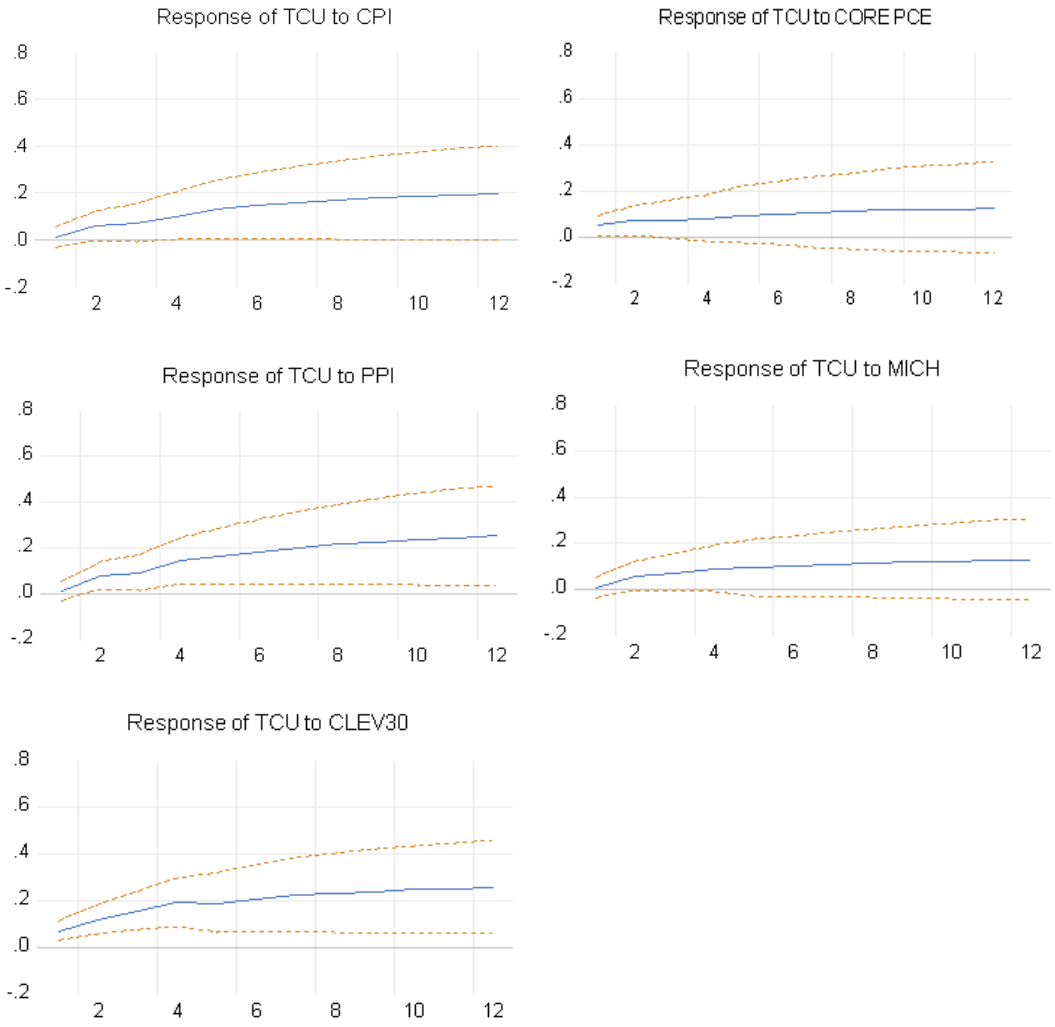
Figure 2. Impulse Response Functions: Accumulated Response of Inflation to a Technology Shock



Note: Dashed lines represent 95% confidence interval bands.

To further analyze the relationship between TCU and inflation, we consider multiple vector autoregression (VAR) to analyze impulse response functions for TCU and each of the current and expected inflation measures. Optimal lag lengths are chosen by the lag length selection criteria. Finn (1996) estimates VAR models and constructs impulse responses to test whether the relationship between capacity utilization and inflation is dynamic over time. Focusing on technology shocks, she finds a positive relationship between endogenous capacity utilization and inflation during technology shocks. Bauer (1990) also finds an endogenous relationship between the two variables during both demand and supply shocks from 1950-1988. Building upon these results, we construct impulse responses to test the response of one of the variables to shocks in the other variable.

Figure 3. Impulse Response Functions: Accumulated Response of TCU to Shocks in Inflation



Note: Dashed lines represent 95% confidence interval bands.

Neither TCU nor any of the measures of inflation or expected inflation respond to a one-time shock in the other variable. When the responses are accumulated, however, CPI, core PCE and PPI all respond to repeated shocks in TCU. Figure 2 displays impulse responses for each of the inflation and expected inflation variables. The graphs represent the accumulated responses of inflation to a one standard deviation shock in TCU. This can be interpreted as a technology shock. Short-term expected inflation, as measured by MICH, also has a positive permanent response to long-term technology shocks but the response is small. The 30-year expected inflation rate does not show any response to a shock in TCU. This implies that expectations of future inflation may be adjusted up slightly, but if the shock is interpreted as temporary, then long-term expectations are unaffected. All of the current inflation variables show a permanent positive impact on prices when there is a shock to capacity utilization.

Figure 3 presents the results when the VAR measures the response of TCU to shocks in current and expected inflation rates. Capacity utilization rates do not respond to shocks to any of the current inflation measures. There is a positive response when the shock is to long-term inflation rates, however. This indicates that firms will adjust capacity slightly when they anticipate higher future prices. This is consistent with the theory of supply. Firms will increase their supply if they anticipate higher future prices.

CONCLUSION

This study analyzes the relationship between capacity utilization and inflation from 1984-2018 alternating price indexes in the models to estimate current inflation as well as short-term and long-term expected inflation. Numerous studies have shown that the relationship between the variables has weakened since the early 1980's. This study attempts to add to the existing literature by analyzing the relationship post 1970's to assess how the relationship may have changed in recent years. Since each inflation index is measured differently, it is important to consider all variables when analyzing this dynamic relationship as some inflation measures have a stronger relationship with TCU than others.

We estimate two forms of OLS regressions with four lags of the dependent and independent variables to capture the lag in response time of each of the variables to one another. The various inflation measures are the dependent variables in the first model and the second model estimates total capacity utilization as the dependent variable. Both models are estimated for the full sample period of 1984-2018 and again on the sub-periods of 1984-1999 and 2000-2018.

Our results show that the relationship between inflation and capacity utilization is complex and has continued to change in recent years. We find that the strongest relationship between TCU and 30 year expected inflation. We find a bidirectional relationship between these variables but the effect of expected inflation on TCU has gotten stronger in recent years while TCU's impact on expected inflation rates has gotten smaller. Additionally, we find TCU has the strongest impact on PPI but find no effect of PPI on TCU rates in our models.

The weakest relationship between TCU and the various inflation measures is with core PCE although core PCE is the only current inflation rate to have any effect on TCU since 2000. These results confirm previous studies that find the relationship between capacity utilization and inflation has weakened since the early 1980's when estimating the relationship using CPI and core PCE for the overall sample. We find the first and second lags of the independent variables in the models to best predictor of changes in the dependent variables for all models of current inflation and short-term inflation.

Long-term expected inflation is the only inflation measure that is found to be statistically significant for the independent variable measured in time t. Additionally, most models were statistically significant in one or more of the lags of the dependent variables as well. This implies that more emphasis should be placed on the relationship between capacity utilization and long term expectations of future inflation rates than on actual inflation.

The Federal Reserve recognizes TCU as an important economic indicator. The accuracy of the Fed's predictions of the current state of the economy is important for investment decisions and these decisions ultimately impact the financial markets. The Fed should not heavily consider capacity utilization rate as an indicator of price pressures especially since it uses Core PCE index as its inflation target objective and this weakest relationship in our results. The Fed should still monitor movements in capacity utilization rates because they are indicators of slack in the economy. Additionally, if rates were to climb to levels similar to those in the late 1960's and early 1970's, then changes in utilization rates could begin to put upward pressure on prices again.

ENDNOTES

1. Personal Consumption Expenditures was also used as an alternative measure of prices but the results were not statistically significant and are therefore omitted from the analysis.
2. As a robustness check, we estimated both models using 10-year expected inflation as measured by the Cleveland Federal Reserve Bank's model and found similar results to the 30-year series. These results are available upon request.

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