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Reassessing Taylor Rules Using Improved Housing Rent Data[☆]

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Abstract

There is a debate whether the federal funds rate deviated from the Taylor rule. We present evidence that standard inflation measures do not reflect the contemporaneous state of housing rents, which is a large part of consumption. Using a new housing rent index (RRI) developed by Ambrose et al. (2015), we compute the RRI-based Taylor rule for the period from 2000 to 2010. The modified Taylor rule indicates that seemingly large deviations are better understood as delays due to the stale information regarding housing rents. It also provides a justification for Quantitative Easing and a better alternative to other versions of Taylor rules.

Keywords: monetary policy, federal funds rate, Taylor rule, Personal Consumption Expenditures, inflation measures, housing rent

JEL Classification: E52; R31; C43; C82

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1. Introduction

What caused the Great Recession of 2007-2008? Answering this question is critically important to policy makers and market participants seeking to avoid similar crises in the future. Unfortunately, nearly eight years after the start of the crisis we are still debating its underlying causes and policy responses. For example, the conclusions reached in the majority and dissenting opinions of The Financial Crisis Inquiry Commission (2011) put forward numerous hypotheses and conjectures on the causes of the crisis such as poor mortgage underwriting (Dell’Ariccia et al., 2012; Jiang et al., 2014; Agarwal et al., 2014, 2015; Garmaise, 2015; Piskorski et al., 2015; Voicu et al., 2015), mortgage securitization (Keys et al., 2009, 2010; Agarwal et al., 2012; Albertazzi et al., 2015), excessive capital availability and liquidity that resulted in a credit bubble (Bruno and Shin, 2015; Che and Sethi, 2014), excessive leverage on the part of households and financial institutions (Campbell and Hercowitz, 2009), declines in household borrowing (Agarwal et al., 2018), and government housing policies (Lehnert et al., 2008; Floetotto et al., 2016; Avery and Brevoort, 2015). A common theme underlying many of these possible causes is an assumption that low interest rates from approximately 2000 to 2005 were a significant causal factor in the housing boom of that period and that this in turn led to the bubble and crash in the housing market in 2007. Central to the assumption that interest rates were too low is the presumption that one can know the appropriate level for interest rates. This presumption is based on comparisons of the actual federal funds rate to interest rates implied by a prescriptive rule for monetary policy. One widely popular rule is the so-called Taylor rule that was first described in Taylor (1993).¹

The Taylor rule is an equation that links the federal funds rate to measures of inflation and output. Taylor (1993) originally developed the rule as a description of the Federal Reserve’s Federal Open Market Committee (FOMC) behavior during its largely successful attempts at stabilization during the “Great Moderation” of the 1980s and 1990s (Clarida et al. (2000)). Because those years were regarded as successful implementation of monetary policy, the rule became as much prescriptive as descriptive and formed the basis for judging the appropriateness of monetary policy in the first decade of the new century. As such, many view the FOMC as setting interest rates too low in the wake of the crash of the tech bubble. For example, Abel et al. (2014) note that “In the 2000s, the federal funds rate has mainly been lower than the level suggested by the Taylor rule.”² However, the interest rate recommendation of the Taylor rule depends of course on the measurements of its inputs, which include measures of output gap (or unemployment), and the rate of inflation. The greater the gap, or the lower the rate of inflation, the lower is the Taylor rule recommendation for the federal funds

¹In fact, Taylor (2007) remarks that if this prescriptive rule had been followed, housing starts would have been far lower from 2003 to 2006, and in fact would have considerably smoothed out the housing boom and bust.

²Abel et al. (2014), pg. 571.

rate. Thus, if inflation or unemployment are incorrectly measured, then prescriptive views of interest rates based on the Taylor rule may not align with actual monetary policy pursued by the FOMC.

For example, Orphanides (2003) suggests that the lack of recognition of the productivity slowdown in the 1960s and 1970s led to the mismeasurement of the output gap in real time (Stark and Croushore, 2002) causing interest rates to be too high relative to what an ex post Taylor rule would have suggested. Inflation mismeasurement in real time did not play as prominent a role. Orphanides and Wieland (2008) find that real time measurement of unemployment provides a reasonably accurate description of Fed policy when that variable replaces the output gap in a modified Taylor rule. Branch (2014) emphasizes the idea that for the effective use of a Taylor rule, the central bank must “nowcast” – that is, use forecasting tools to predict what data agencies will calculate the current values of economic variables are, since the current values are only known with a lag. (We will emphasize shortly that this is a particularly pernicious issue in the use of BLS rent data.) Knotek II et al. (2016) make similar points.

We argue that the FOMC’s estimates of inflation rates were too high for most quarters during the decade 2000-2010, which when inputted into the Taylor rule led critics of the FOMC monetary policy to conclude that interest rates were too low. We make this argument because the estimates of rental costs, which have a very large weight in the calculation of inflation measures, exhibited rates of increase that are largely overstated during this time period. In both Personal Consumption Expenditure (PCE) Chain-Type Price Index and Consumer Price Index (CPI), the rental costs are estimated by the US Bureau of Labor Statistics (BLS) based on repeated surveys of existing tenants. As explained in Ambrose et al. (2015) the BLS rental index is not a contemporaneous view of the state of the housing market because it only measures changes in rents for the existing tenant renewing a lease and omits changes between old and new tenants. Thus, it exhibits a certain amount of downward-stickiness. In contrast, Ambrose et al. (2015) calculate a rental index based on repeated unit-specific observations of new contracts (the Repeat Rent Index, or RRI) that avoids this downward-stickiness bias. The RRI index displays a rate of increase that is substantially lower than that of the BLS during and after recessions. Ambrose et al. (2015) simulate the BLS index construction to confirm that the observed differences between the BLS series and the RRI are not due to differences in the underlying data. Thus, they conclude that the RRI measures weakness in housing market demand that is unobserved when sitting tenants are surveyed. This phenomenon is also related to the time-varying market thickness and household rental duration (e.g., Ngai and Tenreyro, 2014; Halket and Custozza, 2015).

The RRI is a better measure of the inflation rate for housing services for several reasons. First, RRI is theoretically better suited for owners’ equivalent rent, which is a major component of housing in any inflation measure (e.g., comprising 74.2% of the PCE). The owners’ equivalent rent is an opportunity cost for a homeowner, who can potentially rent out a house or move to rental housing. In a housing market

equilibrium, the opportunity cost of owning a house equals the marginal rent for a new tenant in the rental market (e.g., see Summers, 1981; Poterba, 1984; Topel and Rosen, 1988; Mankiw and Weil, 1989). The RRI measures this marginal rent for new tenants. In contrast, the BLS index, which is based on rents for existing tenants, is not consistent with the concept of owners' equivalent rent. Second, every year a large number of households sign new lease contracts either by changing residences or by becoming renters. Wheaton and Nechayev (2009) estimate that the ratio of the number of new lease contracts to the number of existing renters was 29.8% in 2001.³ This ratio tends to increase during recessions when more owners become renters. Thus, RRI is also a relevant rent inflation measure for a large fraction of tenant-occupied housing. Third, the RRI is more reflective of current market conditions than is the BLS existing renter survey. Since the BLS computes the semi-annual average rental growth rate from a sample of existing leases that are typically one year or longer, current rental growth will impact the BLS index only gradually over time. This last point resolves a long-standing puzzle for researchers and real estate investors regarding the inconsistency between the BLS index and the residential real estate investor net income. For example, the correlation coefficient between the apartment net operating income and the BLS index between 2002:I and 2010:I is only 0.16 whereas it is 0.95 between apartment net operating income and the RRI.⁴ Similarly, the apartment rent index by An et al. (2016) is consistent with RRI but not with the BLS index.

We find the following five results when the RRI replaces the BLS rent index in the calculation of inflation measures that are used as inputs into the Taylor rule. First, in sharp contrast to the findings that average federal funds rates were substantially lower between 2000 and 2010 than the rates prescribed when using the traditional PCE based input to the Taylor rule, we find that the actual federal funds rate was greater, on average, than the prescribed rate from the RRI based Taylor rule. Over the entire sample period, the mean gap between the federal funds rate and the rate prescribed by the Taylor rule using the traditional inflation input (Core PCE) is -0.323%, indicating that federal funds rates were, on average, well below the prescribed rates. In contrast, the mean gap between the federal funds rate and Taylor rule using the RRI-Core inflation measure is 0.521%. However, during the critical housing boom period (2003:II to 2005:IV) we still find that actual rates were lower than rates prescribed using the RRI inflation measure. Yet, this period is considerably shorter than the low interest rate period indicated from the Taylor rule based on the traditional inflation measure. Second, during recessionary periods the actual federal funds rates are higher than those prescribed by the RRI based Taylor rule suggesting that the FOMC should have acted more quickly and boldly at critical early stages of the recent recessions. The mean gap for the RRI-Core PCE is 1.428%

³The numbers are 10,272,000 and 34,417,000 for new contracts and existing renters, respectively.

⁴The data for apartment net operating income are obtained from Real Capital Analytics. For the BLS index, we use the PCE price for tenant-occupied housing.

during and around the recession periods. Third, the RRI-based Taylor rule suggests that the federal funds rate should be negative since 2008:IV (the height of the financial crisis), which provides strong justification for the FOMC’s unconventional monetary policy measures (such as Quantitative Easing). Fourth, we show that the deviation in actual federal fund rates from rates prescribed by the traditional Taylor rule reflects both stale information and the BLS focus on existing tenants rather than the marginal renter. Our analysis indicates that the FOMC was actually on target when we use the lagged RRI-based Taylor rule. Finally, the RRI-based Taylor rule is remarkably consistent with an increasingly popular version of the Taylor rule that puts a higher weight on output gap. Thus, this modification in the output weight turns out to be a quick fix of the stale information regarding the housing market and the BLS sitting tenant bias. Overall, since FOMC policy more closely adheres to the RRI adjusted Taylor rule than by the Taylor rule based on the BLS rent index and given that our measure of rental inflation more closely follows contemporaneous movements in the housing market than the BLS index, we interpret our finding as suggesting that the FOMC was aware of the weakness in housing market fundamentals throughout the previous decade and thus was partially adjusting for complex factors in the presence of less elucidated inputs.

In the next section, we provide a brief overview of the Taylor rule and discuss the differences between the RRI and BLS rental indexes. Section 3 presents the results comparing the actual federal funds rate with interest rates derived from the Taylor rule. Finally, section 4 concludes.

2. The Taylor Rule

Our analysis is based on the following basic formulation of the Taylor rule as presented in Taylor (1993):

$$i = \pi + 0.02 + 0.5y + 0.5(\pi - 0.02), \tag{1}$$

where i denotes the nominal federal funds rate, π denotes the rate of inflation over the previous four quarters, and $y = (Y - \bar{Y}) / \bar{Y}$ denotes the percentage deviation of output from full-employment output. As indicated in equation (1), a primary component driving the nominal federal funds rate is the *ex post* rate of inflation (π). Unfortunately, accurately measuring the rate of inflation is a non-trivial matter. For example, the FOMC changed over time the inflation measure to analyze in the Monetary Policy Report; the GNP deflator until July 1988, CPI between February 1999 and July 1999, the PCE deflator between February 2000 and February 2004, and the core PCE deflator since July 2004. Moreover, housing comprises more than 15% of PCE and 30% of CPI yet, it is very difficult to measure changes in the cost to housing – particularly for owner-occupied housing. The PCE price index for housing services is mainly composed of the imputed rental of owner-occupied housing (referred to as owners’ equivalent rent in CPI) and rental of tenant-occupied

housing (referred to as rent of primary residence in CPI). In 2012 these components comprised 74.2% and 24.5% in the PCE housing services, respectively. Since January 1999, the BLS estimates owners' equivalent rent by re-weighting the renter sample in the CPI Housing Survey to match the geographical distribution of owner-occupied units. The correlation coefficient between owners' equivalent rent and rent of primary residence is 0.86 between 1999 and 2012. Thus, the housing rent index is essentially driven by the rent data from the CPI Housing Survey.

In a recent paper, Ambrose et al. (2015) develop a new rental index measure (referred to as the Repeat Rent Index or RRI) that is based on lease contracts that are signed by new tenants, which are more reflective of current market conditions than is the BLS survey of renters in the middle of leases. The RRI is calculated using residential lease transaction data obtained from Experian RentBureau for the period from January 1998 to December 2010.⁵

Figure 1 depicts the RRI and the chain-type price index for housing services in the PCE. Panel (a) depicts the index level and Panel (b) depicts the year-over-year growth rate. As discussed in detail in Ambrose et al. (2015), the RRI marks a sharp contrast with the PCE rent index. First, rents rose more slowly over the decade than would be inferred from the PCE index. In particular, Panel (a) shows that rents leveled off in 2006 and fell during the Great Recession between 2007 and 2009. In contrast, the PCE rent index continued to increase until 2009. Second, the RRI is more volatile than the PCE rent index. Third, the PCE rent index lags the repeat rent index by approximately one year. This is most easily seen in Panel (b). The growth rate bottomed out in 2002:III for RRI but in 2003:IV for PCE. The growth rate increased subsequently and peaked in 2006:I for the RRI but in 2007:I for the PCE.⁶ The last two differences are attributable to the differences in sampling methodology; the RRI is based on the current-period rental change on new contracts with new tenants whereas the CPI rent index is based on the semi-annual average rental growth from the existing renter survey.

We construct the RRI-based inflation (price) indexes for two types of PCE: total PCE and core PCE (i.e., excluding food and energy). To replace the PCE housing rent index with the RRI, we follow U.S. Bureau of Economic Analysis (2012) and use current-dollar PCE expenditures as the relative importance

⁵RentBureau created a national database on tenant rental payment performance collected from property management companies. The data contain information on over 1.4 million lease contracts originated for 551,126 individual residential units in 2,934 multifamily properties. Using the panel of apartment units contained in this data set, Ambrose et al. (2015) construct a time-series of monthly rents paid by a succession of tenants for each apartment unit. From the time-series of monthly rents, Ambrose et al. (2015) created a weighted repeat rent index based on the weighted repeat transaction estimator developed by Bailey et al. (1963), Case and Shiller (1989) and Calhoun (1996) and widely used for constructing constant-quality home price indexes (e.g., the Federal Housing Finance Agency (FHFA) and the S&P Case Shiller Home Price Indexes). Unfortunately, updates to this dataset are no longer available and thus the data best serves as a window to U.S. rental markets during the 2000s.

⁶Ambrose et al. (2015) show that RRI Granger-causes the BLS index.

weights.⁷ Table 1 shows the relative importance of housing services and the core items in PCE from 2000 to 2010. The weight on housing services is approximately 15.3% in the total PCE and 17.6% in the core PCE.⁸ Specifically, for each quarter, we calculate the RRI-based quarterly inflation rate g_m by the following equation:

$$g_m \equiv g_i - w_h g_h + w_h g_r, \quad (2)$$

where w_h is the relative importance weight for housing, g_i , g_h , and g_r are the quarterly price growth rates of the original index, housing services, and the RRI, respectively. Although the BLS calculates owners' equivalent rent by re-weighting the survey sample, the re-weighting scheme cannot be replicated in this study. Thus, we directly apply the RRI to the entire housing services. However, the effect of this omission of re-weighting should not be large because, as noted previously, the owners' equivalent rent is highly correlated with rent of primary residence. Using the quarterly inflation rate, we compute the index level and the year-over-year growth rate.

Figure 2 depicts the RRI-based price index for core PCE items (Panel (a)) and the total PCE (Panel (b)). The core RRI-based indexes exhibit marked differences from the original indexes. For example, the RRI-core PCE was stable during the recession in 2001, increased more rapidly in 2005, and decreased during the recession in 2008 and 2009 whereas core PCE steadily increased throughout the decade (see Figure 2a). The total PCE price index display a similar pattern except that we note a sharp increase and decrease in 2008 due to volatile energy prices (Figure 2b). Figure 3 shows the year-over-year changes. Figure 3a indicates that the RRI-based price indexes are substantially more volatile than the original indexes.

Finally, to parameterize the Taylor rule (equation (1)) we use the real gross domestic product (GDP) as a proxy for output and real potential GDP estimated by the Congressional Budget Office (CBO) for full-employment output. For the rate of inflation, we use (1) core PCE, (2) RRI-based core PCE, (3) total PCE, and (4) RRI-based total PCE. Since the total PCE price is significantly influenced by energy prices, policymakers and researchers tend to prefer core PCE (e.g., Bernanke, 2015). Although the literature has explored various versions of the Taylor rule by using alternative parameters, output gap measures, and inflation measures, we use the most basic version (e.g., Poole, 2007; Taylor, 2007, 2010; Abel et al., 2014; Zimmermann, 2014).⁹

⁷We confirm that these weights give accurate aggregation results by computing the weighted average of quarterly inflation rates for goods and services between 2000 and 2010. The mean difference in quarterly inflation rate between the weighted average and the chain-type price index is 0.003%.

⁸These weights in the CPI items are approximately 32% and 41%, respectively.

⁹We also investigated the Taylor rules using CPI, core CPI, and the GDP deflator. Since the results are qualitatively the same we do not report them here, however, they are available upon request.

3. Results

Figure 4 depicts the federal funds rate and four variations of the Taylor rule. Taylor rules are based on core PCE and the RRI-based core PCE in Panel (a) and the total PCE and the RRI-based PCE in Panel (b). Figure 5 depicts the difference between the federal funds rate and Taylor rules to clarify whether the funds rate is relatively high or low. Following the FOMC, we primarily focus on the core PCE and obtain several key findings.

First, by using the original core PCE index, we confirm the standard result that is reported in the existing studies.¹⁰ For example, Figures 4a and 5a show that the actual federal funds rate was substantially below rates prescribed by the core-PCE based Taylor rule during the period between 2001 and 2005. Poole (2007) observed the same finding and noted that “there are sizable and persistent deviations of the funds rate from the values predicted by the formula.” Taylor (2007, 2010) further argues that “the deviation was larger than in any period since the unstable decade before the Great Modernization” and “the low interest rates added fuel to the housing boom, which in turn led to risk taking in housing finance and eventually a sharp increase in foreclosures and balance sheet deterioration at many financial institutions.”

Second, in a sharp contrast with the findings using the conventional Taylor rules, Figures 4a and 5a show that the actual federal funds rate was above the Taylor rule for more than a half of the sample period (25 out of 38 quarters) when the RRI-based core PCE index is used. Columns (1) and (2) of Table 2 shows the statistical summary of the gap. The mean gap is negative with the original core PCE index but positive with the RRI-based core PCE index. The difference is statistically significant at the 5% level on the basis of the Newey-West HAC standard errors. We still observe that the federal funds rate was lower than the rates prescribed by the RRI based Taylor rule during the housing boom (from 2003:II to 2005:IV). However, this period is much shorter than indicated by the core-PCE based Taylor rule, which began in 2001.

Third, when the RRI-based inflation measure is used, the federal funds rate tends to be higher than the Taylor rule especially during and around recessions. Specifically, the federal funds rate was already higher than the RRI-based core PCE Taylor rule prior to the 2001 recession and continued to be higher until six quarters after the recession. The funds rate was also higher from five quarters before the Great Recession until the end of the sample period. By defining the “period during and around recession” as the NBER recessions and the first and last four quarters of expansionary periods, we estimate the mean gap between the federal funds rate and the Taylor rule on the basis of the RRI-core PCE index (Column (3) of Table 2). The mean gap is 1.43% during and around recession whereas it is -0.87% during the other expansionary

¹⁰Other studies, such as Abel et al. (2014), use the GDP deflator for inflation and also conclude that the federal funds rate is lower than the level suggested by the Taylor rule.

period. The difference in these gaps is statistically significant at the 1% level. These two recessions are critical recessionary periods following the dot-com boom and the housing boom when the FOMC should have been following a monetary policy designed to stimulate the economy. Thus, the Taylor rule using the refined RRI-based inflation measure suggests that the FOMC should have acted more quickly and boldly at the critical early stages of the recent recessions.

Fourth, when the RRI-based core PCE index is used, the Taylor rule suggests negative rates since 2008:IV at the height of the financial crisis. These negative rates provide strong justification for the FOMC's unconventional monetary policy, such as emergency loans to supply liquidity to financial markets, which is also known as Quantitative Easing 1 (QE1). In contrast, the original Taylor rule based on the core PCE suggests only mildly negative rates despite the severity of the financial and housing crises.

However, as the federal funds rate approaches the zero lower bound (ZLB), it provides little insight into the effects of additional unconventional monetary policy. Thus, recent studies suggest using the shadow interest rate originally proposed by Black (1995) to analyze the impact of unconventional monetary policy. For example, Wu and Xia (2016) estimate a three factor model of the term structure of interest rates under the normal interest rate environment and a counterfactual short rate under ZLB (i.e., shadow rate). They demonstrate that the shadow rate is useful in analyzing monetary policy during ZLB periods. Krippner (2012, 2015) argues that a more robust shadow rate can be estimated by a two-factor model. The Reserve Bank of New Zealand updates the shadow short rate data from 1960 based on the model of Krippner (2015)¹¹ Given that our results center on the behavior of rates during this unconventional period, it is interesting to examine whether the RRI-based Taylor rule is more consistent with the shadow short rate than other Taylor rules are.

Figure 6 depicts the Taylor rule that is based on the RRI-Core PCE, the federal funds rate, and Krippner shadow short rate. The Wu-Xia shadow rate is omitted because it is identical to the federal funds rate until 2008 and similar to the Krippner shadow short rate in 2009 and 2010. Both the shadow rate and the RRI-Taylor rule rate are negative during the Great Recession. This is evidence that unconventional monetary policy was more consistent with the RRI-based Taylor rule. Nevertheless, the magnitude of the negative shadow rate is much smaller than the magnitude suggested by the RRI-Taylor rule. Unconventional monetary policy was evidently still not aggressive enough.

The second and third findings are a consequence of stale information in the PCE rent index. To see this, consider that in Figure 1, the PCE rent index lags the RRI by approximately one year. Thus, by relying on

¹¹<https://www.rbnz.govt.nz/-/media/ReserveBank/Files/Publications/Research/Additional%20research/Leo%20Krippner/US-monthly-update.xlsx?la=en>

the core PCE, the FOMC's decisions also appear to lag the peaks and troughs of the RRI-suggested rate by approximately one year. However, once the FOMC started to lower the federal funds rate during the Great Recession, the rate cuts were fast and the funds rate caught up with the Taylor rule in 2008:II.

To confirm this observation, we plot the Taylor rule based on the RRI-Core PCE and the four-quarter lead in the federal funds rate and the Krippner shadow short rate (Figure 7). These three series are more consistent with each other. In other words, if the FOMC were able to use the RRI-based inflation measure, the federal funds rate would have been extremely consistent with the Taylor rule between 2002 and 2006. The sample mean of the gap is 0.02% and statistically indifferent from zero on the basis of the HAC standard errors (Column (4) of Table 2). If the FOMC had used the RRI-based inflation measure, it would have started to decrease the federal funds rate in 2006. This earlier change in monetary policy may have mitigated the severity of the Great Recession. In reality, the severe recession required unconventional monetary policy. As a result, the shadow short rate moved more consistently with the RRI-Taylor rule than the federal funds rate during the Great Recession.

We further investigate the properties of the RRI-based Taylor rule by comparing it with other versions of Taylor rules. First, Figure 8 depicts the RRI-based Taylor rule and the version that Taylor (1999) and Bernanke (2015) advocate. In this version, the coefficient on output gap is increased to 1.0; i.e., the adjusted Taylor (1999) rule is:

$$i = \pi + 0.02 + y + 0.5(\pi - 0.02). \quad (3)$$

Bernanke (2015) suggests that the FOMC has recently paid closer attention to this type of Taylor rule although the theoretical justification for this modification is not clear. These two Taylor rules are remarkably consistent with each other; both Taylor rules suggest a bottom in 2003 when the rates were approximately 1%, a peak in 2006 when the rates were approximately 5%, and another bottom at the end of the Great Recession when the rates were approximately negative 4%. The mean gap between these two versions is 0.02% for the entire sample period. The reason for this consistency is that RRI is highly correlated with output gap; the correlation coefficient is 0.89 during this sample period. This is reasonable because the contemporaneous state of housing market is highly correlated with output.

Second, we further explore the relationship between the RRI-based Taylor rule and the rule that is based on time-varying natural rates of interest. Laubach and Williams (2003) apply Kalman filter to simultaneously estimate time-varying natural rates of interest and the output trend growth. Since the estimated natural rate sharply decreased in 2008 from a range above 2% to near 0%, the Taylor rule based on the natural rate is also significantly impacted (Trehan and Wu, 2007). Figure 9 depicts the Taylor (1993) rule in which we replace the constant 2% real interest rate with the natural rate r^* estimated by Laubach and Williams

(2003):¹²

$$i = \pi + r^* + 0.5y + 0.5(\pi - 0.02). \quad (4)$$

Both rules suggest a sharp decrease in the policy rate during the Great Recession. This comparison result is similar to the result for the Taylor (1999) rule discussed above. This similarity arises because the estimated natural rate of interest is strongly related with the trend growth rate (Laubach and Williams, 2003; Trehan and Wu, 2007). A decrease in the natural rate r^* affects equation (4) whereas a decrease in the output gap y affects equation (3) more strongly. Note that our RRI-based Taylor (1993) rule corrects for a measurement error in inflation rate π in both equations.

However, the RRI-based Taylor rule is markedly different from the Laubach-Williams-based Taylor rule before 2006; the former suggests significantly lower policy rates than the latter. This difference may stem from an important shortcoming of the natural rate, that the estimates are very imprecise and subject to considerable mismeasurement (e.g., Laubach and Williams, 2003; Orphanides and Williams, 2007; Arestis and Sawyer, 2008).

The comparison results discussed above seem to suggest that an increased weight on output gap (Taylor, 1999; Bernanke, 2015) and the use of time-varying natural rates (Trehan and Wu, 2007) work as a quick fix of the stale information regarding the housing market in the original core PCE. However, we emphasize the importance of using correct and timely information on housing rent inflation instead of making a quick fix based on arbitrary weighting or imprecise estimates. Because the correlation between RRI and output gap is not perfect and the estimates of the natural rate are very imprecise, the RRI-based rule diverge from the Taylor (1999) rule around the end of two recessions (Figure 8) and from the rule using the Laubach-Williams natural rate around the end of the recession in 2001 (Figure 9). In particular, the RRI-based rule suggests a higher policy rate toward the end of the sample period. Since 2010, various indicators suggest a much more rapid recovery of housing rents than the output gap or the natural rate.

4. Conclusions

The idea of this paper is simple. The newly constructed Repeat Rent Index (RRI) shows a quite different picture of the housing market from what the PCE rent index indicates. Given that housing rent drives more than 15% of the personal consumption expenditures and 30% of the consumer price index, the use of the alternative (and better in many respects) rent index would significantly change these inflation measures. Moreover, since the PCE price index is a critical factor for monetary policy, the use of the RRI in the

¹²Data are available at https://view.officeapps.live.com/op/view.aspx?src=http%3A%2F%2Fwww.frbsf.org%2Feconomic-research%2Ffiles%2FLaubach_Williams_updated_estimates.xlsx

calculation of PCE price index would significantly alter monetary policy.

To demonstrate the importance of using a more timely measure of housing rent, we compare interest rates prescribed by a Taylor rule using the RRI-based and original core PCE price index over the period from 2000 to 2010, a period when the relevance of monetary policy is intensely debated. In particular, we show that the FOMC's interest rate policy during the controversial 2000 to 2006 period is better explained as a delay due to the stale information about rent appreciation rather than discretion. Although the FOMC appears to have deviated from the Taylor rule and maintained low rates during this period, the path of the federal funds rate closely traces the RRI-based Taylor rule with a one-year lag. Since the PCE rent index lags the RRI by approximately one year, the FOMC's actions would have been consistent with the Taylor rule if it had used more timely information about the (inflationary) housing market environment. Furthermore, unlike the original Taylor rule, the RRI-based rule suggests significantly negative rates during and immediately after the Great Recession, which justifies the unconventional monetary policy of Quantitative Easing. Last, we demonstrate that the RRI-based rule is a better alternative to an increasingly popular version of Taylor rule that puts a higher weight on the output gap or uses the estimated natural rate of interest.

Despite the fact that limitations of the data prevent its use in more contemporary settings, our analysis using the Repeat Rent Index in the critical first decade of the new century highlights the significant problems with housing inflation measures used by the BLS. Our paper can thus be viewed in part as a call for future research attempts to better measure housing rents.

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Year	Total PCE	Housing Services (a)	Core PCE (b)	(a) / (b)
2000	1.000	0.149	0.873	0.170
2001	1.000	0.153	0.874	0.175
2002	1.000	0.153	0.880	0.174
2003	1.000	0.152	0.877	0.173
2004	1.000	0.150	0.875	0.172
2005	1.000	0.152	0.870	0.174
2006	1.000	0.152	0.869	0.175
2007	1.000	0.152	0.867	0.175
2008	1.000	0.154	0.862	0.179
2009	1.000	0.162	0.871	0.186
2010	1.000	0.158	0.868	0.182

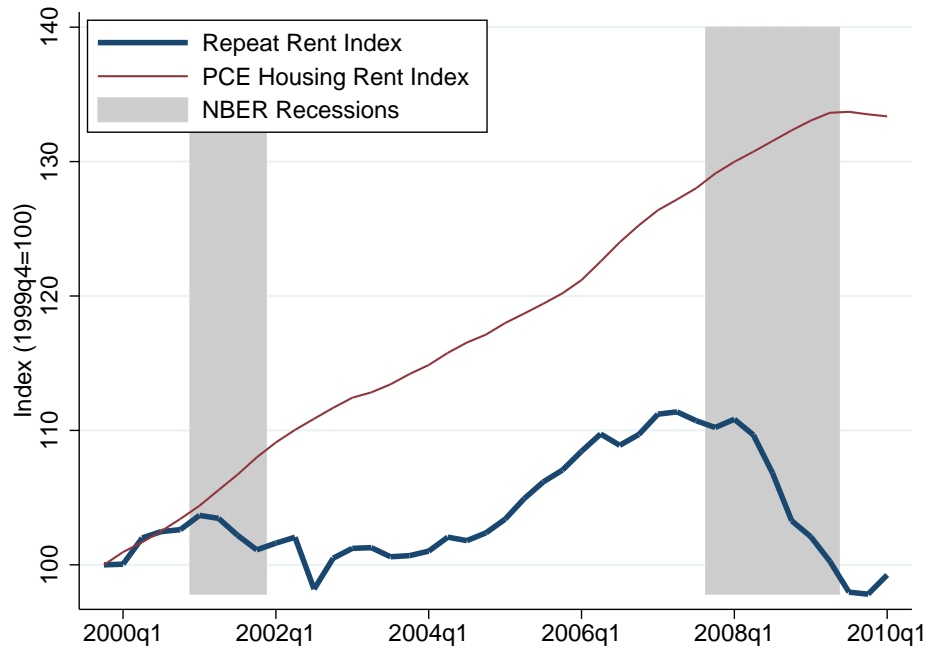
Table 1: The Relative Importance Weights in PCE (yearly average).

Note: The data are obtained from Table 2.4.5U of the National Income and Product Accounts (NIPA).

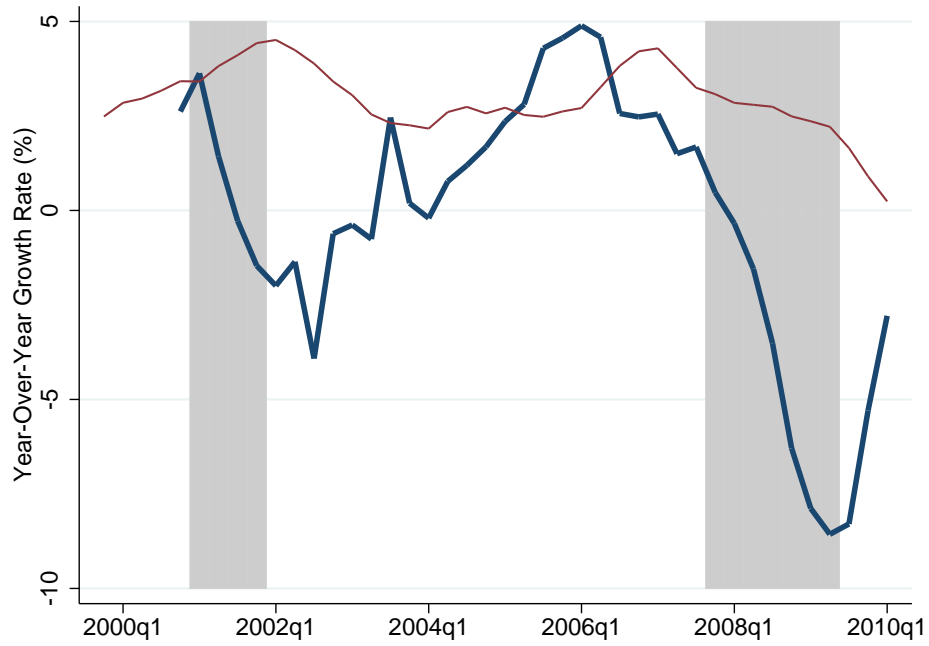
	(1)	(2)	(3)	(4)
Price index used in the Taylor Rule	PCE and RRI-PCE	Core PCE and RRI-Core PCE	RRI-Core PCE	RRI-Core PCE
Federal funds rate	Contemporaneous	Contemporaneous	Contemporaneous	4-quarter lead
Mean gap using the original index	-0.688* (0.397)	-0.323 (0.246)		
Mean gap using the RRI-based index	0.046 (0.513)	0.521 (0.343)		0.017 (0.360)
Difference in gaps	0.734 (0.649)	0.844** (0.422)		
p-value of no difference	0.131	0.024		
Mean gap during and around recessions			1.428*** (0.320)	
Mean gap in other expansionary periods			-0.869*** (0.267)	
Difference in gaps			2.297*** (0.420)	
p-value of no difference			0.000	

Table 2: The Gap between the Federal Funds Rate and Taylor Rules (Funds Rate - Taylor Rule)

Note: This table shows the mean gap between the federal funds rate and Taylor rules. A positive value indicates a high funds rate. In columns (1) and (2), we compare the mean gaps when the original index is used and when the RRI-based index is used. In column (3), we compare the mean gaps for the period during and around recessions and for the other expansionary periods. In column (4), we estimate the mean gap when the four-quarter lead in the federal funds rate is used. For column (3), we report the estimated value of $\alpha + \beta$ from regression: $F_t - T_t = \alpha + \beta R_t + \varepsilon_t$, where F_t is the Fed funds rate, T_t is the Taylor rule, and R_t is the indicator variable for the period during and around recessions. The Newey-West heteroskedasticity and auto-correlation corrected (HAC) standard errors with 1-period lag are in parentheses. The statistical significance is denoted by ***, **, and * at the 1%, 5%, and 10% level, respectively. The p-value is from the one-sided t-test for the null hypothesis of no difference in gap.



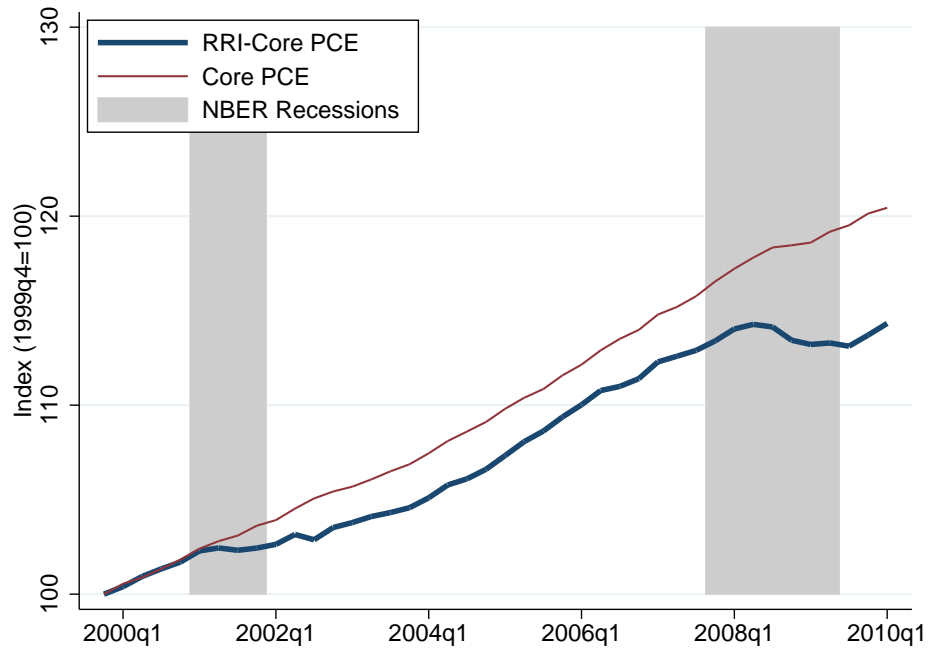
(a) Level



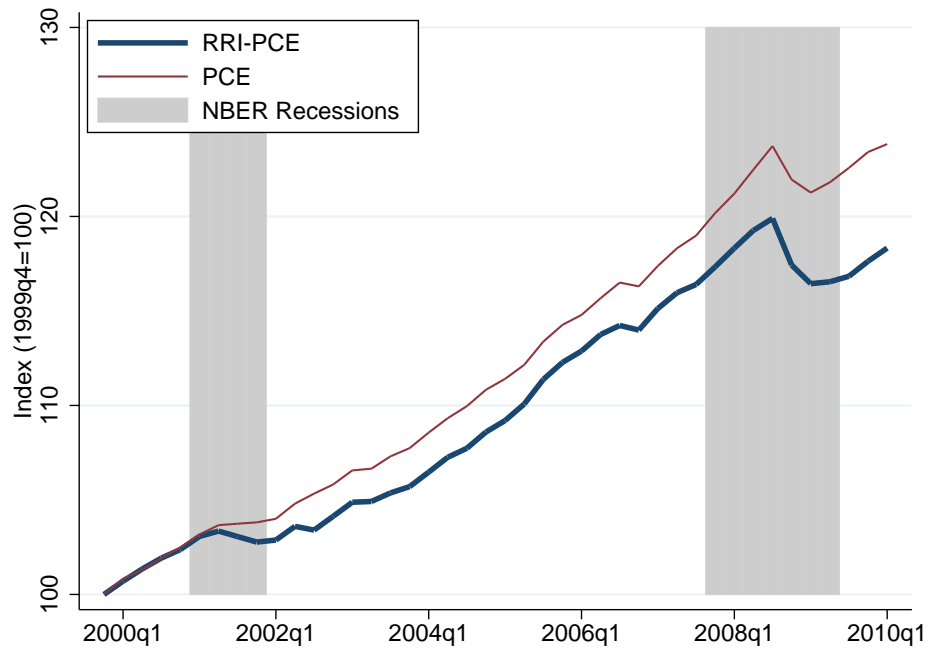
(b) Year-over-year growth rate

Figure 1: RRI and PCE Rent Index.

This figure depicts RRI (developed by Ambrose et al., 2015) and the Chain-Type Price Index for Housing Services in PCE between 2000 and 2010. Panel (a) depicts the index level and Panel (b) depicts the year-over-year growth rate.



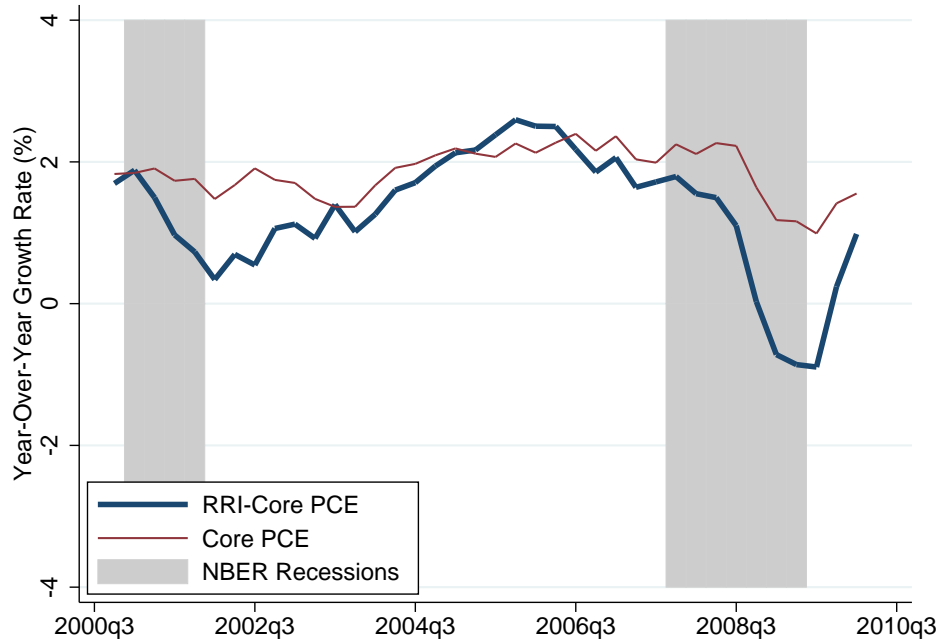
(a) RRI-based and original core PCE



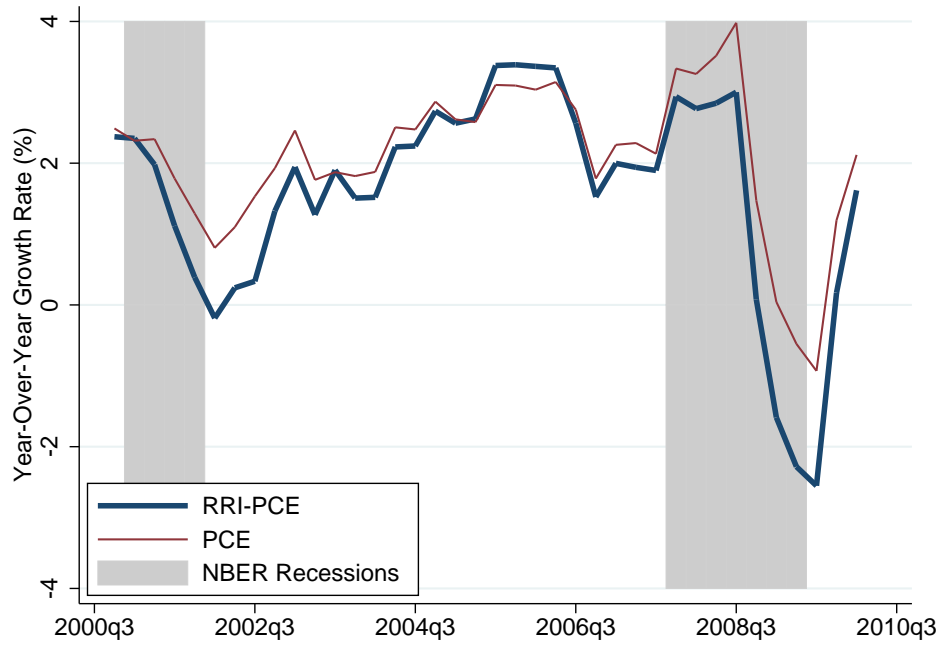
(b) RRI-based and original PCE

Figure 2: Price Indexes.

This figure depicts RRI-based price indexes base on core PCE excluding food and energy (Panel (a)) and total PCE (Panel (b)) between 2000 and 2010. In the RRI-based indexes, the housing service price index is replaced by the Repeat Rent Index developed by Ambrose et al. (2015).



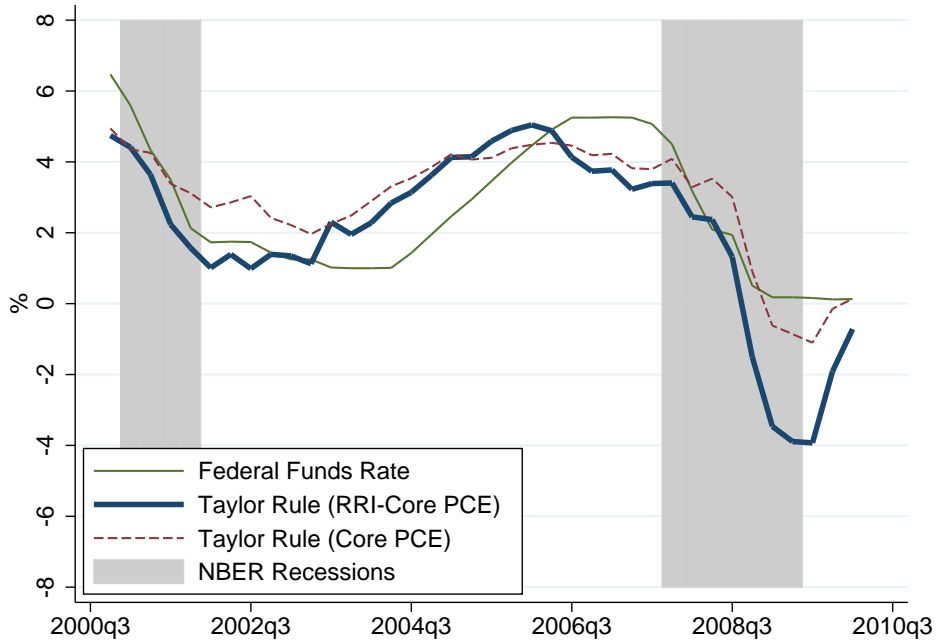
(a) RRI-Based and Original Core PCE



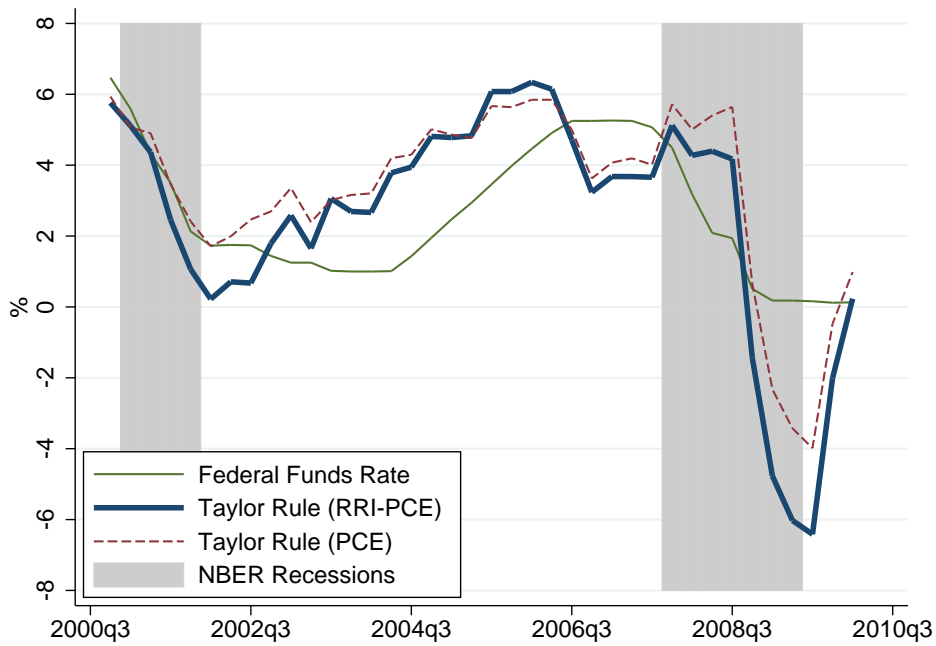
(b) RRI-Based and Original PCE

Figure 3: Year-Over-Year Change in Price Indexes.

This figure depicts the year-over-year growth rates of RRI-based price indexes based on core PCE excluding food and energy (Panel (a)) and total PCE (Panel (b)) between 2000 and 2010. In the RRI-based indexes, the housing service price index is replaced by the Repeat Rent Index developed by Ambrose et al. (2015).



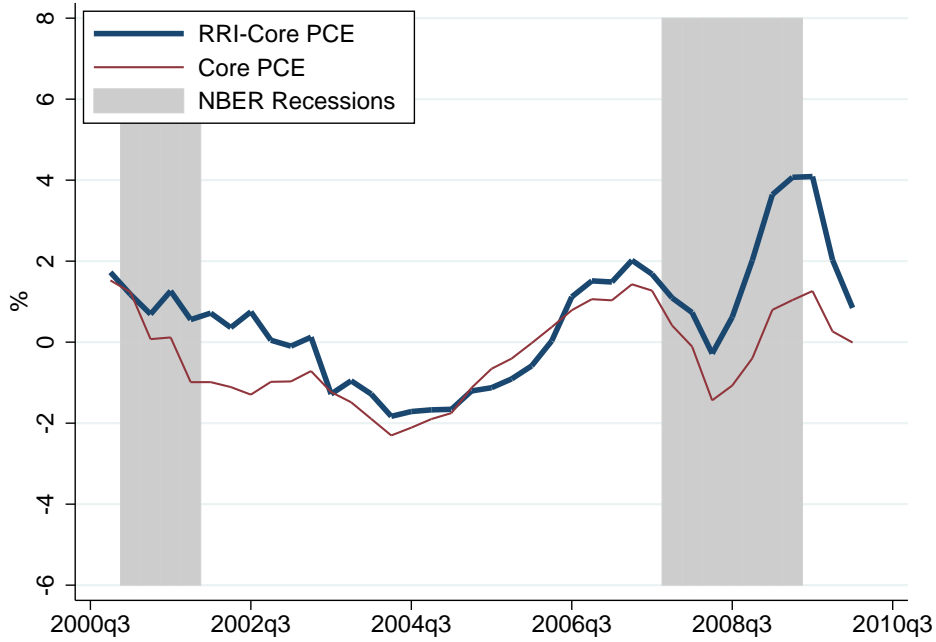
(a) Taylor Rules based on Core PCE



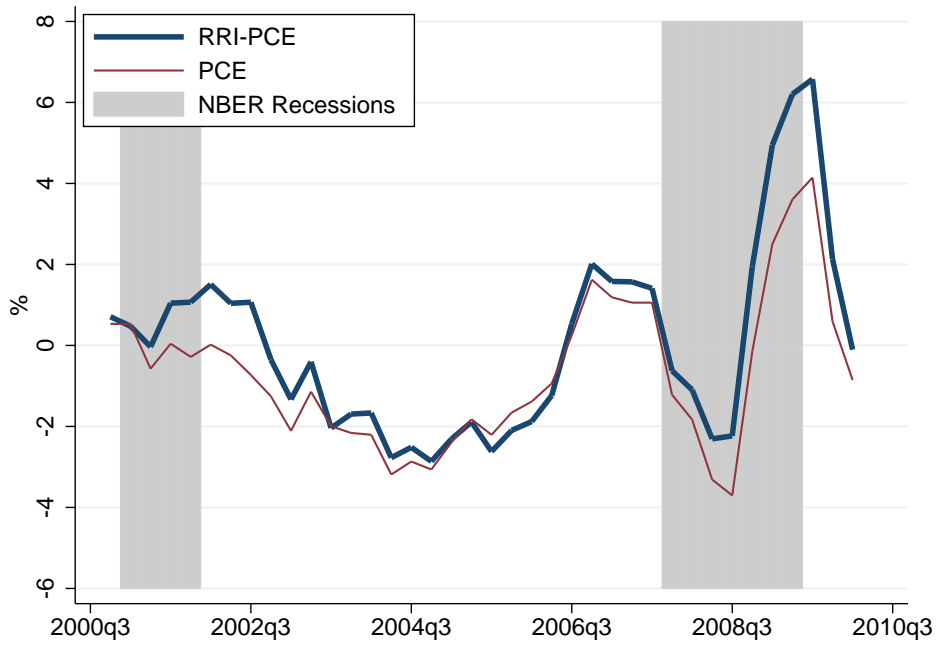
(b) Taylor Rules based on PCE

Figure 4: Taylor Rules and the Federal Funds Rate.

This figure depicts the federal funds rate and variations of the Taylor rule. The Taylor rule is based on the core PCE (excluding food and energy) and the RRI-Core PCE in Panel (a), and PCE and the RRI-PCE in Panel (b). The RRI-based indexes are based on the Repeat Rent Index developed by Ambrose et al. (2015).



(a) Gaps based on Core PCE



(b) Gaps based on PCE

Figure 5: Difference Between the Federal Funds Rate and Taylor Rules.

This figure depicts the difference between the federal funds rate and the Taylor rule. A positive value indicates that the federal funds rate is relatively high. The Taylor rule is based on the core PCE (excluding food and energy) and RRI-Core CPI in Panel (a), and PCE and RRI-PCE in Panel (b).

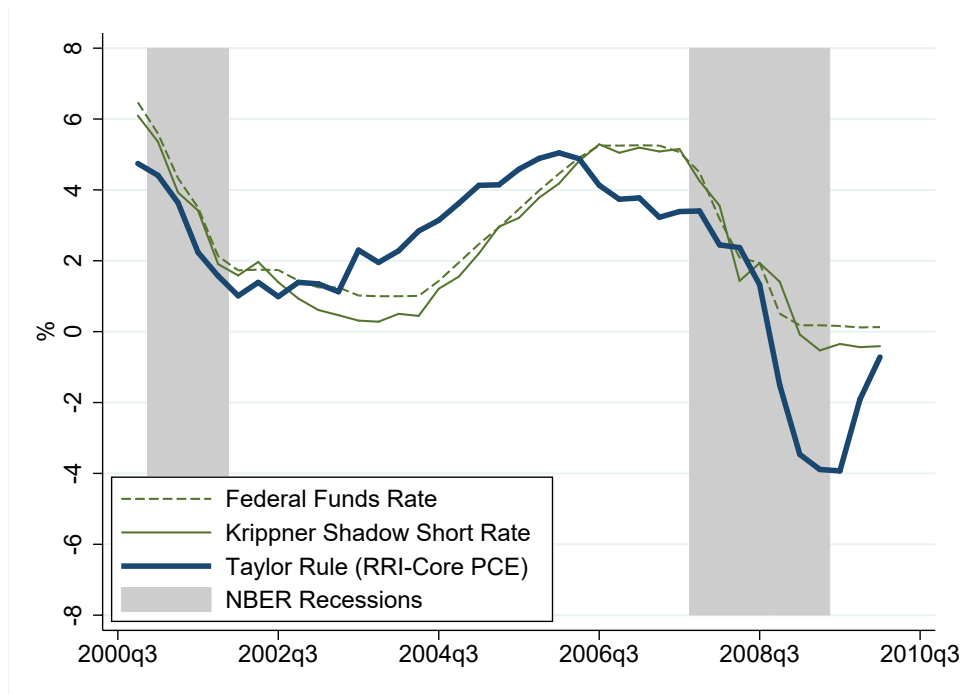


Figure 6: The Shadow Short Rate and the RRI-based Taylor Rule

This figure depicts the Taylor rule that is based on the RRI-core PCE (excluding food and energy), the federal funds rate, and the Krippner shadow short rate. The RRI-based indexes are based on the Repeat Rent Index developed by Ambrose et al. (2015). The Krippner shadow short rate is available from the Reserve Bank of New Zealand.

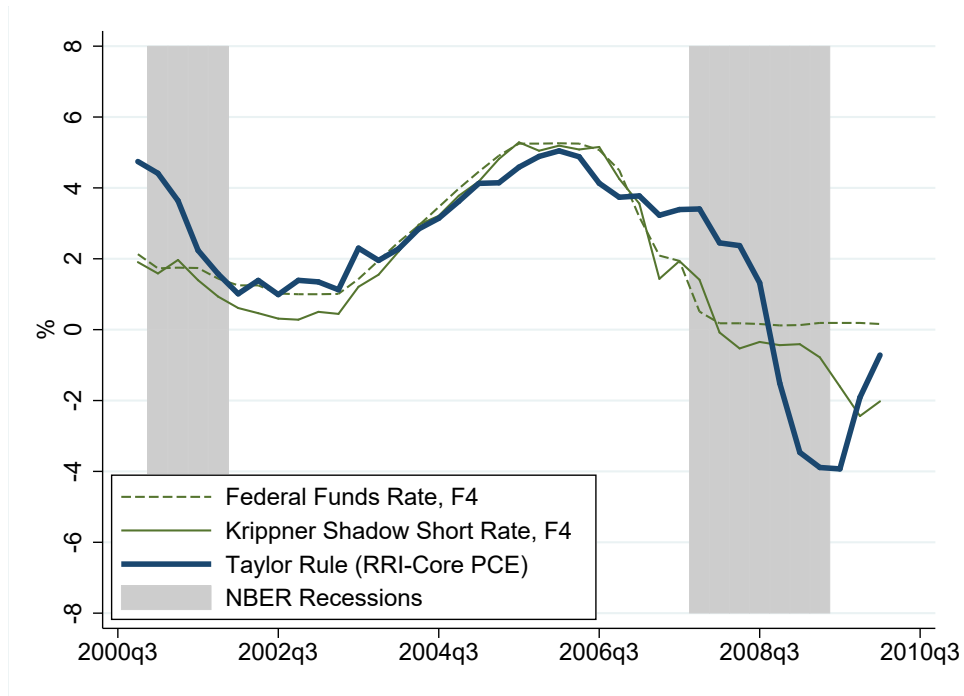


Figure 7: The Four-Quarter Lead in the Federal Funds Rate.

This figure depicts the Taylor rule that is based on the RRI-core PCE (excluding food and energy) and the four-quarter lead in the federal funds rate and the Krippner shadow short rate. The RRI-based indexes are based on the Repeat Rent Index developed by Ambrose et al. (2015).

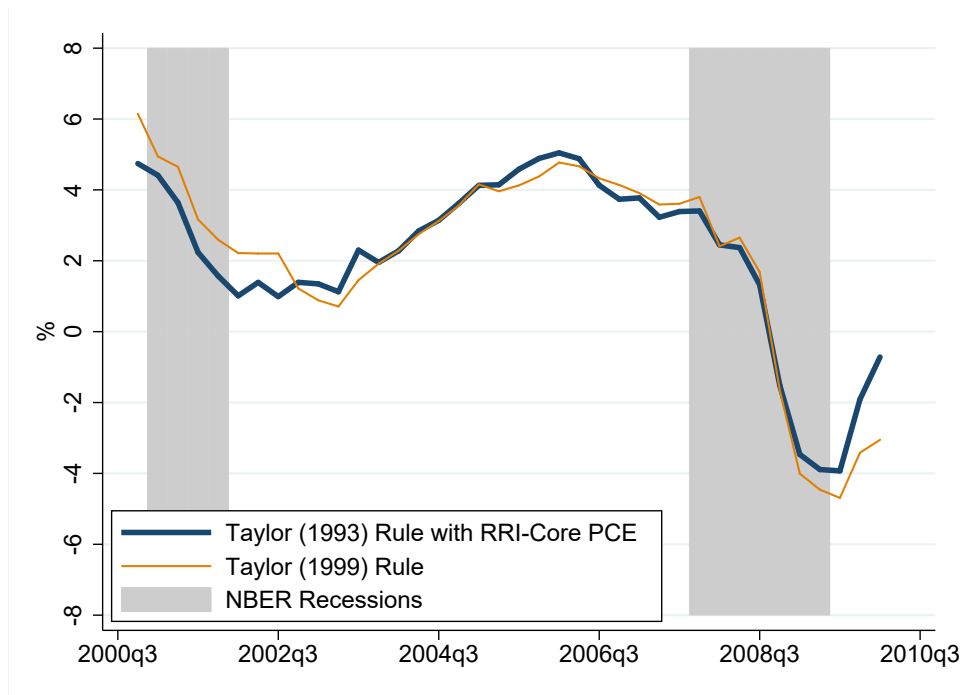


Figure 8: The RRI-Based Taylor (1993) Rule and the Taylor (1999) rule.

This figure compares two versions of Taylor rules: the version by Taylor (1993) that uses the RRI-based core PCE price index and the version by Taylor (1999) and Bernanke (2015). The former is: $i = \pi + 0.02 + 0.5y + 0.5(\pi_{RRI} - 0.02)$, where i denotes the Federal funds rate, π_{RRI} denotes the RRI-based core PCE inflation rate over the previous four quarters, and y denotes the output gap. The latter is: $i = \pi + 0.02 + y + 0.5(\pi - 0.02)$, where π denotes the core PCE inflation rate over the previous four quarters. The RRI-based indexes are based on the Repeat Rent Index developed by Ambrose et al. (2015).

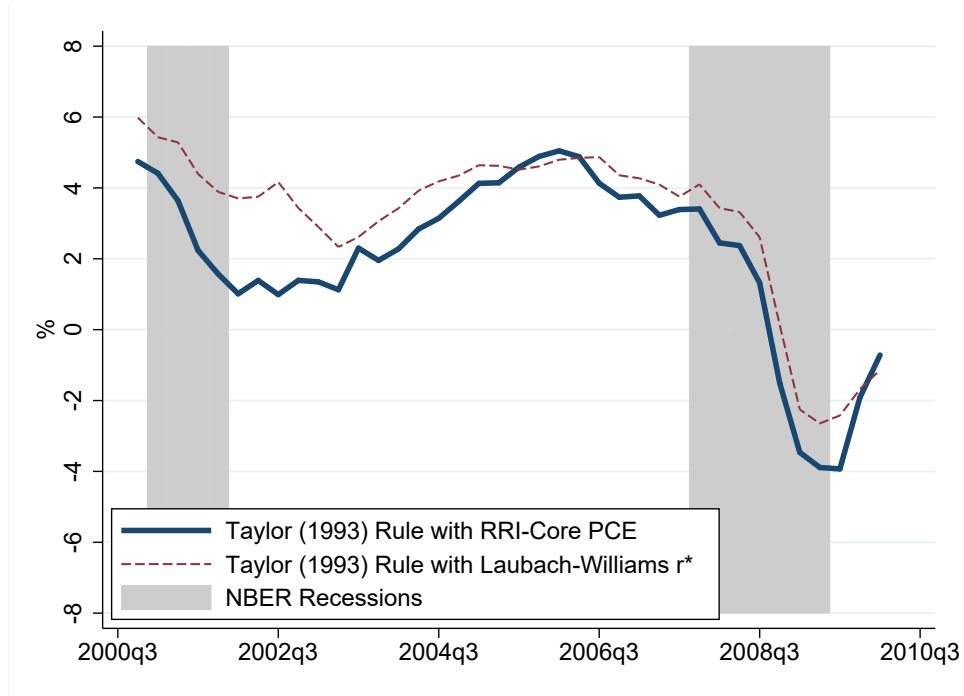


Figure 9: Taylor Rules Based on the RRI-Core PCE and Laubach-Williams Natural Rate.

This figure compares two versions of Taylor (1993) rules: one with the RRI-based core PCE price index and the other with the natural rate of interest estimated by Laubach and Williams (2003). The RRI-based indexes are based on the Repeat Rent Index developed by Ambrose et al. (2015).