Housing Rents and Inflation Rates

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Abstract

This paper demonstrates that inflation rates are significantly modified when they are based on the alternative quality-adjusted measure of housing rents constructed from a monthly statistic of landlord net rental income. The official rate was overestimated by 1.7 to 4.2% annually during the Great Recession but underestimated by 0.3 to 0.9% annually during the current expansionary period. We further demonstrate significant impacts of the modified inflation rates on Social Security and real gross domestic product. These impacts persist for a long term because the modified indexes are integrated of order one whereas the official indexes are trend stationary.

JEL classification: E01, E31, R31, H55.

Keywords: measurement error, economic statistics, owners' equivalent rent, Consumer Price Index, Personal Consumption Expenditures, National Income and Product Accounts.

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I. Introduction

Official price indexes, such as the Bureau of Labor Statistics' (BLS) Consumer Price Index (CPI) and the Bureau of Economic Analysis' (BEA) Personal Consumption Expenditure (PCE) Price Index in the national income and product accounts (NIPAs), are susceptible to measurement errors (Hausman, 2003). A number of academic researchers and government commissions have pointed out various issues and have helped improve the official price indexes (see the surveys by Hausman, 2003; Lebow and Rudd, 2003; Reinsdorf and Triplett, 2009). The major issues identified as problematic include substitution effects and aggregation methods (e.g., Diewert, 1976; Manser and McDonald, 1988; Aizcorbe and Jackman, 1993; Shapiro and Wilcox, 1996), quality changes in existing goods (e.g., Moulton and Moses, 1997; Shapiro and Wilcox, 1996; Lebow and Rudd, 2003), sample representativeness and introduction of new goods (e.g., Gordon, Davis, and Rich, 1993; Griliches and Cockburn, 1994; Shapiro and Wilcox, 1996), shifts in shopping patterns (e.g., Reinsdorf, 1993; Shapiro and Wilcox, 1996), relative importance weights (e.g., Lebow and Rudd, 2003), and including owner-occupied housing in the CPI (e.g., Diewert, 2009).[1]

The impact of measurement errors can be enormous because these price indexes are the basis of a wide range of economic statistics, contracts, public policy programs, asset prices, and most importantly, corporate and consumer decision making. For example, real gross domestic product and productivity growth are estimated by deflating nominal values by price indexes. A number of contracts and public programs are indexed to CPI; e.g., Treasury Inflation Protected Securities (TIPS), lease contracts, labor contracts, social security, and income tax brackets. Monetary policy is often evaluated on the basis of measured inflation rates. Especially in recent years, there are growing debates on the "missing disinflation" during the Great Recession and a breakdown of the Phillips curve (e.g., Hall, 2013; Coibion and Gorodnichenko, 2015; Summers, 2017). Finally, the expected future inflation rate is an

[1] More recently, the stochastic nature of measurement error is under investigation (e.g., Svensson and Woodford, 2004; Handbury, Watanabe, and Weinstein, 2015; Aoki, 2006).

important component of the discount rate and thus, it critically affects consumption and investment.

We demonstrate a new source of bias that is caused by measurement errors in housing rents. Since changes in housing rents comprise a significant portion of price inflation and given the importance of housing to the economy, we focus on how differences in measuring the housing component affect the construction of the CPI and PCE price indexes. We then demonstrate that current estimates of housing rent inflation, which understate the variation in the actual rent inflation with significant lags, can have material and economically significant effects on a variety of economic policies and decisions.

To confirm the role of housing in overall measures of inflation, Figure 1 and Table I show the relative importance of housing in the CPI and PCE indexes between 1997 and 2017. In 2016, the shelter price (or housing component) accounted for 33.3% of the CPI and 42.0% of the core CPI, excluding food and energy. Housing services, which are the PCE equivalent of the CPI shelter component, accounted for 15.8% of all items and 17.7% of the core items.[2] Breaking down the housing components, the CPI and PCE include the consumption of housing services by persons who own the housing that they occupy (i.e., the imputed rent for owner-occupied housing) as well as by those who rent their housing. Table II shows that owners' equivalent rent comprises 73.8% of CPI shelter while the rent of primary residence accounts for 23.6%. These relative weights of the housing components are similar in the PCE housing services.

Since housing is an integral component of the CPI and PCE inflation indexes, it is thus directly linked to numerous academic studies and public policies. As a result, even small changes in the housing component of inflation can have impacts on such diverse areas as consumer welfare calculations (e.g., Bajari, Benkard, and Krainer, 2005), macro-economic

[2]The variation in these weights stems from errors in the Consumer Expenditure Survey and the difference in the coverage of goods and services. For example, the PCE includes goods and services purchased on behalf of households (e.g., medical care premium payments made by the employers and by the government) whereas the CPI reflects only out-of-pocket expenditures of all urban households. The PCE also includes the imputed cost of financial services that do not involve out-of-pocket expenditures.

studies of possible price bubbles (e.g., McCarthy and Peach, 2004, 2010; Himmelberg, Mayer, and Sinai, 2005; Campbell and Shiller, 1988; Brunnermeier and Julliard, 2008; Verbrugge, 2008; Campbell, Davis, Gallin, and Martin, 2009; Summers, 1981), interest rates (e.g., Taylor, 1993a,b; Clarida, Gali, and Gertler, 2002, 2000; Ambrose, Coulson, and Yoshida, 2018), tax policies (e.g., Poterba, 1984), tenure choice decisions (e.g., Sinai and Souleles, 2005; Halket and Custoza, 2015), housing price index construction (e.g., Gatzlaff and Haurin, 1997; Clapp, Giaccotto, and Tirtiroglu, 1991; Clapp and Giaccotto, 1998; McMillen and Thorsnes, 2006; Meese and Wallace, 1997; Shiller, 1991), and housing rental rates (e.g., Genesove, 2003; Eichholtz, Straetmans, and Theebe, 2012). Cecchetti (2007) notes the increased importance of inflation targeting by central banks and notes that "The big question for inflation measurement is how to handle housing."

The BLS estimates rental cost inputs for the CPI shelter and PCE housing services components using repeated surveys of existing tenants. The survey result is used to estimate both renters' and owners' shelter costs. There are two major approaches to estimating owners' shelter costs: the user cost approach and the rental equivalence approach. The former approach adds user cost components such as real estate taxes, insurance, interest, and changes in the property price whereas the latter approach is based on market rents for rental housing. The BLS has been using the rental equivalence approach since January 1983 for All Urban Consumers (CPI-U) and January 1985 for Urban Wage Earners and Clerical Workers (CPI-W).

The surveys tend to underrepresent new tenants but overrepresent sitting tenants. Thus, the CPI and PCE price index mainly capture moderate changes in rents for existing tenants and miss larger rental updates that result upon tenant turnover. As Ambrose, Coulson, and Yoshida (2015) discuss at length, this sampling method introduces several biases in the rental cost estimate. First, the BLS index tends to underestimate rent appreciation during expansionary periods and overestimate it during recessionary periods because it mainly reflects the renewal rent for existing tenants.[3] In addition, the underrepresentation of new leases is exacerbated during recessions when tenant turnover increases. As a result, the BLS index did not exhibit significant depreciation in recent recessions.[4] Second, as noted by Verbrugge (2008), the BLS index construction method introduces additional smoothing effects by averaging the rent for each survey month and then calculating the six-month average growth rate on a rolling basis (i.e., January-July, February-August, etc.). Third, the BLS rent index lags contemporaneous rent measures. For example, if all leases are annual, then only $1/12^{\text{th}}$ of the BLS sample will reflect market conditions with some observations reflecting economic environments that are nearly a year old. Thus, the BLS index only gradually incorporates market information, lagging the contemporaneous market rent measure by approximately one year.[5]

To overcome these biases, Ambrose, Coulson, and Yoshida (2015) propose a new rental index based on repeated unit-specific rental contracts (the Repeat Rent Index, or RRI). The RRI is a quality-adjusted rent index that measures the marginal rent for newly-signed lease contracts with new tenants. In the RRI data, the survey omission issue is absent because they are based on lease payments to landlords. The RRI exhibits large rent depreciation during the Great Recession, greater volatility than the BLS index, and Granger causality with the BLS index. Ambrose, Coulson, and Yoshida (2015) confirm that these differences do not stem from variation in sample characteristics but rather from differences in index construction. Unfortunately, one shortcoming of the RRI is that it ends in 2010, limiting its

[3]Crone, Nakamura, and Voith (2010) note that the omission of rent changes due to tenant turnover likely biased downward the CPI by 1.4% per year between 1940 to 1985. Lane, Randolph, and Berenson (1988) and Gordon and vanGoethem (2007) also provide evidence supporting the downward bias. Gallin and Verbrugge (2007) discuss improvements to the BLS methods for measuring inflation. Furthermore, in defense of the CPI, Verbrugge and Poole (2010) argue that differences in local rental patterns within cities account for much of the differential between observed rent inflation and the shelter component (the Owners' Equivalent Rent, or OER).

[4]Although Crone, Nakamura, and Voith (2010) note that these problems have been partly addressed by major revisions in the CPI Housing Survey, Ambrose, Coulson, and Yoshida (2015) demonstrate that significant biases still exist in the 2000's. In addition, Ozimek (2014) demonstrates a similar bias using market rents on single-family rentals in the Baltimore/Washington, D.C. area while Shimizu, Nishimura, and Watanabe (2010) find a similar bias in the Japanese CPI rents.

[5]See Ambrose, Coulson, and Yoshida (2015) for analysis of the lag structure.

use for analysis of the period following the Great Recession.

To rectify the truncation of the RRI series, we propose a new method for estimating inflation in housing service prices. Our new series, called the Net Rent Index (NRI) is based on the Moody's/RCA Commercial Property Price Index (CPPI) for apartments.[6] The CPPI is a quality-adjusted repeat sale index. By multiplying the monthly CPPI by the monthly average multifamily capitalization rate (i.e., income yield), we obtain a consistent monthly index of net rental income that is based on arm's length market transactions and reflects cash flows from both new and existing leases. After converting the data between 2001 and 2010 to a quarterly series, we validate that the NRI tracks the RRI with a high degree of precision – having a correlation of 0.858 in growth rates from a year ago. In contrast to the CPI rental component and consistent with the RRI, the NRI reveals that rental rates fell consistently during the Great Recession and then rebounded with double-digit yearly increases after 2010. By construction, the NRI is fully consistent with the recent property price boom and bust.[7]

Having verified that the new NRI captures important characteristics of the housing market that are missed by the CPI rental component, we next demonstrate that actual inflation rates may have varied substantially from reported rates. To do so, we replace the CPI/PCE rent index with the NRI-based rent measure. Specifically, we use the NRI to construct an additional derivative rent measure, the Marginal Rent Index (MRI), which represents gross marginal rents. We then substitute the rental price of tenant-occupied housing and the imputed rental price of owner-occupied housing in the CPI/PCE with this Marginal Rent Index. We use time-varying importance weights for these items to construct four modified chain-type price indexes: all-item CPI, core CPI, all-item PCE, and core PCE.

Our analysis reveals that significant biases exist in the official inflation measures especially since 2007:12 at the start of the Great Recession. The official all-item inflation rates were

[6] For detailed description of the index, see `https://www.rcanalytics.com/our-data/rca_cppi/`

[7] The apartment property price index appreciated by 79.5% during the housing boom in the 2000's (2001:I-2007:IV). During the same period, the NRI appreciated by 32.2%, and the capitalization rate decreased by 26.0%. A similar result is obtained with other data (e.g., the CoStar multifamily index).

1.1 to 1.2% during the recession whereas the modified inflation rates were −0.6 to −2.1%. Similarly, the official core inflation rates were 1.5 to 1.9% whereas the modified rates were −0.4 to −2.3%. The upward bias ranges from 1.7 to 4.2% per year. In contrast, during the expansionary period since 2009:7, the official inflation rates are significantly lower than the modified rates. The official all-item inflation rates are 1.5 to 1.7% whereas the modified rates are 1.8 to 2.4%. Similarly, the official core inflation rates are 1.5 to 1.7% whereas the modified rates are 1.9 to 2.6%. The downward bias ranges from 0.4 to 0.9% per year. Thus, measurement errors in housing rents cause biases in both directions. The fundamental issues related to these biases are underestimated volatility and significant lags in the official rent measure.

In order to assess the long-run implication of the modification, we examine the time-series property of the price indexes. For example, if an index has a unit root, then an inflation shock will have a permanent impact on the price level. However, if the modified index is cointegrated with the official index, then the modification will make a small difference in the long-run. The Phillips-Perron unit root test shows that the original price indexes are trend stationary whereas the modified indexes are integrated of order one, or $I(1)$. The trend stationary price index is consistent with the idea of the Great Moderation (e.g., Stock and Watson, 2002; Bernanke, 2012; Clark, 2009). However, our modification makes the price index $I(1)$ as Nelson and Plosser (1982) find using the data before the 1980's. Thus, the measurement of housing rents significantly impacts how we characterize the economy with important implications for the assessment of the long-term impact of economic shocks.

We further present two example applications that demonstrate the economic significance of the bias: Social Security benefits and real gross domestic product. The first application considers an impact on the Social Security benefits, which are indexed to the CPI inflation rate (i.e., cost-of-living adjustments or COLAs). Following the financial crisis, the COLAs based on our modified CPI would have been 0.8% per year higher. Thus, for an individual in 2016 who had been a beneficiary for 5 years, cumulative benefits using the modified

COLAs would have been 6.3% higher. In dollar terms, the monthly benefit for a 70-year old individual who retires in 2016 would be $167 greater and the difference in total Social Security system benefit payments would be approximately $24.2 billion.

The second application considers an impact on the calculation of real gross domestic product (GDP). Our modification to the PCE price deflator has a direct effect on the real PCE as well as real GDP because nominal expenditures and price deflators are estimated with different statistics. If our modified deflator had been used, the decrease in real GDP during the Great Recession would have been more moderately estimated: −5.1% per annum in 2008:IV as compared with the official figure of −8.5%. In contrast, the average real economic growth rate would have been smaller after the recession: 2.0% per annum between 2009:III and 2016:I as compared with the official figure of 2.2%. Thus, once measurement errors in housing rents are corrected, the U.S. economy has been growing at 2.0% per year following the Great Recession, but the core inflation rate has been 2.4%. Our analysis suggests that the U.S. may be experiencing a 'stagflation' period.

Our paper is organized as follows. In the next section, we discuss the variety of data sets used to construct alternative housing rent indexes. Section III describes how we construct and validate our new rent indexes and modify the CPI and PCE price indexes. Section IV then compares the official price indexes with our modified price indexes. In section V, we turn to a few applications to demonstrate the economic significance of accurately measuring housing rent inflation. Finally, section VI concludes.

II. Data

A. Repeat Rent Index

In order to illustrate the effect of different rental rates on inflation calculations, we assemble data from a variety of sources. First, we utilize the repeat rent index (RRI) as developed in Ambrose, Coulson, and Yoshida (2015). The RRI is based on residential rent transactions reported by Experian RentBureau for the period from January 1998 to December 2010.[8] Ambrose, Coulson, and Yoshida (2015) document that the RRI is more volatile than the BLS rental data that are used in the CPI and PCE price series. They also show that the BLS lags the RRI indexes, suggesting that the BLS rental series do not track current market conditions. In a follow-up study focused on optimal monetary policy, Ambrose, Coulson, and Yoshida (2018) recalculate the CPI and PCE indexes by substituting the RRI index for the housing component. They demonstrate that the RRI-based price indexes differ substantially from the original CPI and PCE indexes.[9] Their analysis also confirms that this difference is not caused by the underlying sample characteristics such as geographical weights.

Table III demonstrates that the BLS rent index (and equivalently, PCE and CPI rent indexes) lags the RRI as Ambrose, Coulson, and Yoshida (2015) point out. The table shows the F-statistic and the adjusted R-squared of a regression: $g_{PCE,t} = \alpha + \beta g_{RRI,t-n} + \varepsilon$, where $g_{PCE,t}$ is the percentage change from a year ago in the PCE rent for tenant-occupied housing, $g_{RRI,t-n}$ is the n-quarter lagged percentage change from a year ago in the RRI, and ε is the error term. Both statistics are largest when the RRI is lagged by 5 quarters. The implied correlation coefficient between these two indexes is 0.94 when the 5-quarter lagged RRI is used.

B. Commercial Real Estate Data

While the RRI developed by Ambrose, Coulson, and Yoshida (2015) has distinct advantages in measuring housing rent inflation, it unfortunately suffers from a serious drawback – it is unavailable after December 2010. In order to overcome this shortcoming, we assemble a new database comprising repeat property transactions to create a new net rent index (NRI).

We use the commercial apartment data provided by Real Capital Analytics (RCA) as

[8] Ambrose and Diop (2014) provide a more complete description of the RentBureau data.

[9] In addition, Ozimek (2014) finds a similar pattern in the Baltimore-Washington, D.C. single-family rental market; and single-family data from CoreLogic also produces a similar result.

the backbone for constructing our NRI. RCA is a major provider of commercial real estate transaction data, which is one of the most comprehensive datasets covering investment grade properties. The firm provides two types of information that is relevant for our research: residential property transaction prices and capitalization rates (cap rates).

A cap rate is defined as a property's expected annual net operating income (NOI) divided by its current transaction price. The NOI equals the gross rental income less operating expenses and is equivalent to the income from net rental contracts. Thus, a cap rate also measures net rent per square foot normalized by the price per square foot. RCA collects the information on either the expected NOI or the cap rate for each transaction, and publishes the national average cap rate and the property price index. Thus, by combining the cap rate information with the price information, we can recover the net rent information for residential real state. An advantage of RCA's net rent information is its timeliness because investors report the forward-looking measure of net rents based on the most recent lease contract.

The difference between gross rents and net rents is operating expenses such as property management costs, property taxes, and maintenance costs. According to the 2017 National Apartment Association Survey of Operating Income and Expenses, the proportion of these costs to potential gross income are 18.2% for property management costs, 11.5% for property taxes, and 3.7% for maintenance costs. Utility costs are small (2.7%) because the majority of rental apartments (95.7%) are individually metered. Most operating expenses are fixed and unaffected by short-term rental market conditions.

The RCA's property price index is published as the Moody's/RCA Commercial Property Price Index (CPPI). The CPPI is a monthly repeat sale index starting in December 2000. The CPPI is publicly available and produced on a timely basis making it invaluable for constructing updated measures of housing rental prices. This index comprises transactions from domestic and foreign institutional and private investors but excludes non-arm's length and other non-standard transactions. The national index covers 20 states and 34 metropolitan markets. For a property to be included in the index, RCA requires that the first transaction in the repeat-sale pair be greater than $2.5 million in 2010 constant value and the prices are not adjusted for routine capital expenditures.[10]

The properties in the RCA apartment sample are similar to the properties underlying the RRI in that they tend to be larger complexes. For example, the RCA Cap Rate Sample, which is the source data for the Moody's/RCA CPPI repeat sale index, contains an average of 375 transactions per month. The average property in the sample has 167 units and is valued at $14.9 million (for an average price per unit of $90,600.) These statistics are comparable to the descriptive statistics for the properties underlying the RRI as reported in Ambrose, Coulson, and Yoshida (2015) and Ambrose and Diop (2014). As a result, the RRI and CPPI reflect relatively large, institutional grade properties.

Since the RCA and RRI samples are based on relatively large, professionally managed properties, a concern is that the properties comprising our index may not reflect the sample underlying the BLS index, which includes many smaller, non-professionally managed rental units. However, Ambrose, Coulson, and Yoshida (2015) confirm the consistency between the samples underlying the RRI and BLS rent indexes. First, they use the entire RentBureau sample of both new and existing tenants to simulate the BLS index construction. Since the simulated rent index is consistent with the official BLS rent index, Ambrose, Coulson, and Yoshida (2015) conclude that "if the BLS had used the RentBureau sampling methods, its indexes would look much the same as before" (p. 948). Second, Ambrose, Coulson, and Yoshida (2015) also confirm that the differences in the BLS and RRI are not due to temporal variation in the RentBureau sample. As a result, we feel that it is not the differences between RRI/RCA and BLS samples that is responsible for the variation in inflation measures.[11] Third, at the micro-location level, the characteristics of the RRI index (rent depreciation during the Great Recession and greater volatility than the BLS index) are similar

[10] Unfortunately, we do not know the exact geographical criteria used in the CPPI sampling and thus we use the national average CPPI.

[11] Rather, Ambrose, Coulson, and Yoshida (2015) demonstrate that the differences are due to variation in index construction methods.

to the Washington, DC area repeat rent index reported in Ozimek (2014), which is based on single-family rental listings contained in a multiple listing service (MLS) database. Thus, the consistency between the RRI and the single-family rental based index in Ozimek (2014) provide additional comfort that the differences between the RRI/RCA and BLS sample are not driving our results. Finally, in an analysis of rent changes using confidential micro-data from the BLS for the periods 2001-2004 and 2004-2007, Verbrugge, Dorfman, Johnson, Marsh, Poole, and Shoemaker (2017) find weak statistical evidence for, at most, a modest influence of structure type on rent inflation.[12] As a result, we believe the preponderance of the evidence indicates that differences in property types comprising the BLS and RRI/RCA samples are not driving our results.

C. Net Rent Index

We construct the NRI, a quality-adjusted net rent index by multiplying the CPPI by the average cap rate for apartments. The advantages of the NRI are that it is a forward-looking net rent measure, is based on arm's length market transactions, is based on repeat sale index, comprises a consistent rent type (net rent), and is updated monthly. Figure 2 shows the CPPI and corresponding cap rates.

The timeliness of NRI stems from the forward-looking nature of cap rates. When calculating cap rates, investors use the best estimate of the average NOI for the coming year instead of the realized NOI for the past year. Since the lease term is one year for the majority of residential leases in the U.S., most leases will be either renewed or replaced with new leases during the coming year. It can be demonstrated that the projected NOI correctly captures peaks and troughs of the marginal rent dynamics under some conditions (Appendix A). For example, if investors on average make the correct estimate of the low-frequency component

[12] Verbrugge, Dorfman, Johnson, Marsh, Poole, and Shoemaker (2017) report that four of the eight structure indicator variables are statistically significant in pooled regressions where the dependent variable is the change in rent over a three-year period (p. 615). Furthermore, Verbrugge, Dorfman, Johnson, Marsh, Poole, and Shoemaker (2017) note that their robustness check "likewise suggests that structure type is not strongly and systematically related to rent change" (p. 617).

of marginal rent growth, the projected NOI for the coming year will correctly capture the contemporaneous marginal rent growth process. The intuition is that for each leasing unit, the time average of projected rents for the coming year will approximately equal the current marginal rent. In contrast, the BLS rent index lags marginal rents approximately by one year.

To validate our NRI as a measure of the rental market, we present in Table IV the pairwise correlation coefficient between percentage changes from a year ago in alternative rent indexes during 33 quarters between 2002:I-2010:I. The NRI reflects the average net rent for both new and existing tenants. In contrast, the RRI and the PCE rent reflect gross rents for new tenants and existing tenants, respectively. The NRI is highly correlated with both the RRI (the coefficient is 0.858) and the 5-quarter lead PCE rent (the coefficient is 0.884). The coefficient between the RRI and the 5-quarter lead PCE Rent is even larger (0.950). However, the contemporaneous PCE Rent exhibits small correlation coefficients with other indexes. This result confirms the discussion by Ambrose, Coulson, and Yoshida (2015) that the BLS rent index lags the contemporaneous market rent by approximately one year because of its sampling and index construction method. Figure 3 depicts the quarterly NRI, the 5-quarter lead PCE Rent, and the RRI. The results shown in the table and figure clearly indicate that the NRI, the RRI, and the lead PCE rent reflect the common dynamics of rental housing markets. The key difference between these three indexes is volatility.

Table V presents the mean and standard deviation of quarterly percentage changes in alternative rent indexes during 36 quarters between 2001:II and 2010:I. The PCE rent is the least volatile with the quarterly standard deviation of 0.333%. This is because the index construction method has several smoothing effects (Verbrugge, 2008). In particular, the PCE rent reflects mostly renewal rents for the same existing tenants due to the BLS survey design. Thus, the PCE rent represents an infra-marginal rent in the rental market. In contrast, the RRI is more volatile than the PCE rent (the quarterly standard deviation is 1.394%.) The RRI reflects newly contracted rents at the time of tenant change (i.e., marginal rents). These changes are usually larger than the changes in renewal rents for the existing tenants. The NRI is more volatile than the RRI (the quarterly standard deviation of NRI is 2.335%) although the NRI reflects rents for both new and existing tenants. This is because net rents are calculated by subtracting largely fixed operating expenses from gross rents (i.e., operating leverage).

III. Construction of the Modified Price Indexes

A. Concepts of Rents

The price of housing services is mainly composed of two elements: the rental price of tenant-occupied housing and the imputed rental price of owner-occupied housing.[13] Table II shows the weight of each element in the CPI and the PCE price. For both price indexes, approximately a quarter is for tenant-occupied housing and three quarters are for owner-occupied housing. We consider the appropriate measure for each element of housing rents.

First, we note that the economic concept of owners' equivalent rent (i.e., the imputed rent of owner-occupied housing) 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; Topel and Rosen, 1988; Mankiw and Weil, 1989). It also implicitly reflects the user cost of housing: the cost of capital, property taxes, maintenance and repair costs, and the expected depreciation or appreciation in the property value (e.g., Poterba, 1984). Thus, owner's equivalent rent is different from the long-term fixed rent that was available at the time of home purchase. Although the long-term rent is based on the expected future rents, the realized rent deviates from the initial expectation because of shocks to user costs. A constant rent for a long lease term is usually followed by a large change in rents between

[13] In CPI, the former is termed the rent of primary residence and the latter is termed owners' equivalent rent.

leases. Thus, the relevant measure of owners' equivalent rent is marginal (gross) rents for each period.

Second, we note that the rent of tenant-occupied housing should reflect the average gross rent for both new and existing tenants. The estimated annual turnover rate (the ratio of new lease contracts to the total renters) is approximately 30 to 34%.[14] Rent changes are typically much smaller for existing tenants than for new tenants; rents are fixed during a lease term and adjusted only moderately at a lease renewal for existing tenants. After several renewals, the rent for an existing tenant typically deviates from the market rent. When tenants change after several lease renewals, the difference between old and new rents is often much larger than the change in the marginal rent for a single period.[15] However, the average change in rents for all existing and new tenants approximately equals the change in the marginal rent in any given period. Thus, the relevant measure for the rent of tenant-occupied housing is also marginal gross rents.

To see how the marginal rent inflation is related to the average rent inflation, RRI, and renter surveys, consider the following hypothetical case. The lease term is one year, and each tenant uses the same unit at a constant rent for two years. One half of the renters (Group E) change rental units in even-numbered years; they move at $t = 0, 2, 4, ...$ and renew leases at $t = 1, 3, 5, ...$ The other half (Group O) change rental units in odd-numbered years; they move at $t = 1, 3, 5, ...$ and renew leases at $t = 2, 4, 6, ...$ Marginal rents increase by 5% every year. Thus, when a new renter moves in, the rent for a unit increases by 10.25% ($1.05^2 - 1$).

In this case, the RRI inflation rate is 5% every year. For example, the RRI inflation rate between $t = 1$ and $t = 2$ is estimated with the information for both renter groups: The 10.25% inflation between $t = 0$ and $t = 2$ for Group E and the 10.25% inflation between $t = 1$ and $t = 3$ for Group O. The estimated inflation rate is 5% for the overlapping period.

On the other hand, the average inflation rate is 5.125% for a given year because a half of

[14] Wheaton and Nechayev (2009) estimate the turnover rate is 29.8% for 2001 (10,272,000 new contracts to 34,417,000 renters). Crone, Nakamura, and Voith (2010) estimate the average rate between 1970 and 2002 is 34.4% by using Vacancy Survey, American Housing Survey, Census, and Residential Construction Survey.

[15] See Velsey (2018) for various anecdotes.

renters experience a 10.25% increase whereas the other half experience no change. The difference between the geometric mean (5%) and the arithmetic mean (5.125%) become smaller as time intervals become shorter. Thus, the rate of the average rent inflation approximately equals the rate of marginal rent inflation.

Furthermore, consider an annual renter survey that is sent to a subsample of Group E when they become new tenants at $t = 0$. They report the initial rent and the same renewal rent at $t = 1$ indicating a 0% inflation rate for this period. After they move out at $t = 2$, if new tenants for all of these units participate in the survey, the measured inflation rate will be 10.25% between $t = 1$ and $t = 2$. Then, the geometric mean inflation rate over two years is 5%. However, if no new tenant participates in the survey, the 10.25% inflation rate is not recognized. An additional survey can be sent to different units at $t = 2$, but the data for different units cannot be combined with those for the original units. Thus, when some of new tenants do not participate in the survey, the estimated inflation rate is biased toward the inflation rate of renewal rents for sitting tenants.

B. Marginal Rent Index

We construct the modified price indexes by using the relevant measure of housing costs for each of the two elements. Although the RRI is best suited for this purpose, as we discuss above, the index cannot be extended after 2010. Thus, using the NRI, we construct the Marginal Rent Index (MRI), which has the same mean and standard deviation of quarterly growth rates as the RRI. Specifically, we first standardize the monthly percentage change in the NRI with zero mean and unit sample variance ($g_{snri,t}$). Then, we adjust the mean and standard deviation of monthly changes in the NRI until the mean and standard deviation of quarterly changes become equal to those in the RRI. The estimated conversion equation from the standardized NRI to MRI is for each month t: $g_{mri,t} = -0.03927653 + 0.4850342 \times g_{snri,t}$. Using the monthly MRI change $g_{mri,t}$, we compute the monthly index level, percentage changes from a year ago, and the quarterly percentage change. Table V shows the matched mean and standard deviation for MRI and RRI for the overlapping period between 2001:II and 2010:I. The MRI is extended until 2017:11 and can be updated monthly. Figure 5 also confirms a good fit of these two indexes. Thus, we use the MRI as the relevant measure for owners' equivalent rent.

C. *Modified Inflation Rates*

Using the MRI, we derive the modified inflation rate by replacing the rental price of both tenant- and owner-occupied housing with the MRI. Specifically, we compute:

$$i_{mod,t} \equiv i_{ori,t} - w_{h,t} g_{h,t} + w_{h,t} g_{mri,t}, \tag{1}$$

where $i_{mod,t}$ and $i_{ori,t}$ are the modified and original monthly inflation rates, respectively. The inflation measure can be based on all or core items. We let $w_{h,t}$ denote the relative weight for housing (shelter). These weights change every month for PCE and every year for CPI as shown in Figure 1 and Table I.[16] We let $g_{h,t}$ and $g_{mri,t}$ denote monthly percentage change in the original housing service price and the Marginal Rent Index, respectively. We further compute the price index level and percentage change from the previous quarter and the previous year.

Since we simply replace the official rent index with our rent indexes, one may suspect that we fail to take into account substitution effects. In other words, when housing services become relatively expensive, housing services may become less important in a price index because consumers may switch away from housing services to relatively less expensive goods and services. However, substitution effects are not a serious concern to our modified index for three reasons. First, we use time-varying importance weights to construct a chained

[16] The relative importance for CPI is available at: `http://www.bls.gov/cpi/cpiriar.htm`. For the PCE, we follow U.S. Bureau of Economic Analysis (2012) and use current-dollar PCE expenditures as the relative importance weights. We 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 official chain-type price index is 0.003%. The weight in 2017 is extrapolated from 2016 for CPI.

price index. Thus, substitution effects are incorporated in our index. Second, the elasticity of substitution between housing services and other goods is very small. For example, the estimated elasticity of substitution is between 0.4 and 0.9 (Davidoff and Yoshida, 2013), and the estimated price elasticity of housing services is between -0.8 and -0.3 (Mayo, 1981; Harmon, 1988; Ermisch, Findlay, and Gibb, 1996; Green and Malpezzi, 2003). Thus, a change in relative prices does not induce a large impact on housing services consumption. Third, as Hausman (2003) emphasizes, substitution effects are a second-order effect whereas measurement errors in housing rents have the first-order effect.

Our strategy effectively extrapolates the relation between indexes before and during the Great Recession into the period after the recession. Thus, this strategy depends on the stability of relations between indexes. To validate the relevance of this strategy, we test the structural break in the relation between indexes before and after the Great Recession. Since the 13-month lead PCE and the NRI are available throughout the entire sample period, we examine the relation between these two indexes. As Figure 6 depicts, monthly percentage changes in these two indexes are positively correlated both before and after the recession. The correlation coefficient is 0.59 for both periods. We formally test the structural break by the Chow Test. The regression equation is:

$$g_{pce,t+13} = \beta_0 + \beta_1 g_{nri,t} + \beta_2 D + \beta_3 \left(D \times g_{nri,t}\right) + \varepsilon, \tag{2}$$

where D denotes a dummy variable that takes the value of one after the Great Recession (2009:7-2016:10). Rejecting the hypothesis that $\beta_3 = 0$ would indicate a structural break in the relation between these two indexes. The data period is between 2001:4-2016:10. Table VI shows the test result based on the Newey-West heteroskedasticity and autocorrelation corrected standard errors. The estimated β_3 is not statistically significant at any conventional level. Thus, we conclude that there is no evidence for a structural break in the relation between the NRI and the 5-quarter lead PCE before and after the Great Recession.

Another concern is that vacancy rates might distort the NRI. The NRI measures the landlord net income from the occupied units. Since the vacancy rates change over the business cycle, the NRI reflects changes in both net rental rate and vacancy rates. Panel (a) of Figure 4 depicts the percentage change from a year ago in NRI and the national rental vacancy rate published by the U.S. Bureau of the Census. The NRI is negatively correlated with vacancy rates (−0.74). In particular, vacancy rates increased from 9.6 to 11.1% during the Great Recession when the NRI inflation rate plunged from 5.6 to −18.3%. However, the effect of vacancy rates on NRI is not large. We construct the Vacancy-Adjusted Net Rent Index by dividing NRI by 1 minus vacancy rates. Panel (b) of Figure 4 demonstrates that the difference is negligible. Table VII shows the summary statistics of these two indexes and the test result about equal means and variance. The Vacancy-Adjusted NRI is less volatile only by a small margin; we do not reject the null hypotheses of equal means or equal variance.[17] Furthermore, because the correlation coefficient is 0.985 between quarterly changes in NRI and Vacancy-Adjusted NRI, these two indexes are effectively identical time series (Table VIII). Thus, vacancy rates make virtually no impact on Net Rent Index.

IV. Result

We now turn to the primary focus of our study – demonstrating that the actual inflation rate would vary substantially from the reported series if one were to correct for the problems associated with the BLS rental series. Figures 7 - 10 depict the original and modified price indexes. Each figure shows the index level (panel (a)), the percentage change from a year ago (panel (b)), and the difference between these two rates (panel (c)). Tables in our Web Appendix present the monthly and quarterly estimated values.[18]

Figure 7 shows the modified all-item CPI. In 2005 at the height of the housing boom,

[17] Vacancy rates increase the volatility of NRI because of a contemporaneous negative correlation with rents. However, quarterly changes in vacancy rates are not large; the standard deviation is 0.34 percentage points.

[18] http://www.personal.psu.edu/juy18

the modified CPI increased slightly faster than the original CPI. However, generally in the 2000's until a few months after the Great Recession, the modified CPI increased more slowly than the original CPI. In particular, the modified index exhibits sharp deflation as large as 5.8% during the Great Recession. In contrast, in the current expansionary period starting in 2009:7, the modified CPI started to increase faster than the original CPI by 0.7% per year. Figure 8 also exhibits a similar result for the all-item PCE although the difference is more moderate because of the smaller importance of housing in the price index. In particular, inflation rates are largely identical until the beginning of the Great Recession. However, we observe that the modified index deviates negatively during the Great Recession and positively during the current expansionary period after the recession. The most severe deflation rate was 3.3%. The difference between two inflation measures is approximately 0.3% in the current expansionary period.

Figures 9 and 10 exhibit similar but sharper contrasts for core inflation measures than for the all-item measures. Although the original core inflation measures do not exhibit any deflation since 2001, the modified core measures show sharp deflation during the Great Recession. The deflation rate reached 3.7% for the core CPI and 1.5% for the core PCE price; the rate difference was 4.2% for the core CPI and more than 1.9% for the core PCE price in this deflationary period. In the current expansionary period, the modified core inflation measures are greater than the original core measures by approximately 0.9% for CPI and 0.4% for PCE.

Table IX summarizes the annualized average monthly inflation rate for four different time periods defined by the NBER recession status. The table also presents the difference in inflation rates between the original and modified inflation measures. During the recession between 2001:3 and 2001:11, the average inflation rates were not very different between the original and modified measures: e.g., 0.9-1.2% in the original all-item measures and 0.8-1.3% in the modified all-item measures. In the following expansionary period between 2001:12 and 2007:11, the average inflation rate was 2.5 to 2.9% in the original all-item measures and

2.3 to 2.4% in the modified all-item measures. Thus, there were moderate upward biases during this period by 0.2 to 0.5%. However, biases became significantly larger during the Great Recession between 2007:12 and 2009:6. The original all-item inflation rates were 1.1 to 1.2% but the modified all-item inflation rate was −2.1% for CPI and −0.6% for PCE. The upward bias was 3.3% for CPI and 1.7% for PCE. Biases were even greater for core measures: 4.2% for core CPI and 1.9% for core PCE. The official inflation measures did not reflect large deflation in housing rents. In contrast, during the expansionary period after the Great Recession, the direction of bias is reversed; there were 0.3-0.7% downward biases in the all-item measures and 0.4-0.9% downward biases in the core measures. During this recovery period, the official measures did not reflect large inflation in housing rents. Thus, measurement errors in housing rents caused biases in both directions depending on the business cycle. Therefore, the major issues are underestimated volatility and significant lags in the official rent measure.

The positive difference (i.e., greater inflation rates by the modified measures) in the current expansionary period may give us a clue to resolving a puzzle regarding the unconventional monetary policy after the Great Recession. The puzzle is that "official" inflation rates did not respond to monetary policy as many policymakers expected despite its unprecedented scale.[19] However, we show that inflation rates exhibited greater responses based on the alternative housing rent measure. In particular, the modified core PCE inflation rate exceeded the 2% threshold in 2011:7 and has been consistently higher since then. Thus, this improved measurement has an important implication for monetary policy.

In order to assess the long-run implication of the modification, we examine the time-series property of the price indexes by testing whether they are diffusions or trend stationary and whether the modified index is cointegrated with the original index. For example, if an index has a unit root, then an inflation shock will have a permanent impact on the price level. However, if an index is trend stationary, then the effect of an inflation shock is temporary. If

[19] The Federal Reserve started the Large Scale Asset Purchases (LSAPs) in December 2008 (so-called QE1) and continued them until November 2014 (so-called QE3).

the modified and original indexes are diffusions and the modified index is cointegrated with the original index, then the modification will make a small difference in the long-run.

Table X shows the results of the Phillips-Perron unit root test. The Augmented Dickey-Fuller test also provides qualitatively the same result. The reported numbers are the MacKinnon approximate p-values of failing to reject the null hypothesis that the variable contains a unit root. We obtain a very clear result that the modified indexes have unit roots whereas the original indexes do not. For example, the p-value for the original core CPI is 0.00 whereas the p-value for the modified core CPI is 1.00 for any number of lags. In contrast, the p-value for the first difference is 0.00 for all indexes. Thus, the original price indexes are trend stationary whereas the modified indexes are integrated of order one, or $I(1)$. This obviously means that the modified index is not cointegrated with the original index.

The price index was found by Nelson and Plosser (1982) to be I(1) based on data before the 1980's. This conclusion was modified by Stock and Watson (2002),Bernanke (2012), and Clark (2009) who found that it was trend-stationary in later periods, an idea consistent with the great moderation. However, our recalculation of inflation suggests that inflation was in fact I(1) at least since the beginning of our sample in 2000, a finding which has an important implication for the role of our modification. When we measure the price level by the modified index, an inflation shock has a permanent effect on the price level. The difference between the original and the modified index is also persistent. Thus, the sample applications that we demonstrate in the next section are important in the long run.

V. Applications

We now turn to two example applications that demonstrate the economic significance of the differences between the original and modified inflation measures. Our first application considers the impact of the modification to CPI on the Social Security Administration's annual cost-of-living adjustments (COLAs). Social Security benefits are indexed to inflation in order to protect beneficiaries from the loss in purchasing power associated with rising prices. Thus, mis-measuring inflation can have a profound affect on the segment of the population most at risk to loss of purchasing power (the elderly living on fixed incomes.) Our second application considers how the change in the PCE price index can impact calculations of the real Gross Domestic Product (GDP). Since economic growth and fluctuations are measured using real GDP, mismeasurement of the index that deflates nominal GDP can distort fundamental macroeconomic analysis.

A. Cost-Of-Living Adjustments

As noted in the introduction, a variety of contracts and programs are linked to changes in the CPI. As a result, differences in measured inflation between the BLS CPI and our NRI-based CPI can have profound effects on these contracts and programs. For example, the CPI-W is used as the index for yearly COLAs for determining Social Security (OASDI) and Supplemental Security Income (SSI) benefits.[20] Burdick and Fisher (2007) provide an overview of the issues associated with COLA calculations and discuss the controversy surrounding the use of various CPI's in determining the yearly adjustments. Furthermore, Burdick and Fisher (2007) and Goda, Shoven, and Slavov (2011) note that the use of the CPI-W in current COLA calculations significantly mis-measures actual inflation experienced by the elderly due to the differences in medical expenses, housing costs, and shopping habits of the elderly versus the general population. For example, Goda, Shoven, and Slavov (2011) suggest that the net-of-medical-spending benefit for a man born in 1918 declined by approximately 20% between 1983 and 2007.

To illustrate the effect that differences in the housing inflation measures can have on Social Security benefits, we consider the differential impact of switching the actual CPI

[20]Since 1975, Social Security and SSI benefits are automatically adjusted to reflect increases in the cost-of-living as measured by the BLS CPI-W. Prior to 1972, Social Security benefits were enacted on an ad hoc basis by Congress. The current COLA calculation is set in December each year based on the percentage change in the average CPI-W in the third quarter over the previous year's third quarter average. (See the "Cost-Of-Living-Adjustment Fact Sheet" distributed by the Social Security Administration at `https://www.ssa.gov/pubs/EN-05-10526.pdf`.)

with our modified CPI in calculating the annual COLAs. Figure 11 shows the actual annual COLAs reported by the Social Security Administration.[21] Since the CPI-W reported declines from the previous years in 2008 and 2009 as well as in 2014, the actual COLAs report no adjustment for years 2009, 2010, and 2015. Figure 11 also reports the estimated COLA based on the modified CPI as well as the yearly differential (actual less modified). Since our modified CPI reports higher increases than the CPI-W, the modified COLA would have resulted in no adjustment in only 2009. The differential is illustrated by the bars in Figure 11.

Over the period from 2003 to 2017, the COLAs based on the modified CPI would have been 0.3% per year higher than the actual COLAs. However, following the financial crisis, COLA adjustments using the modified CPI would have been 0.8% per year higher. Table XI reports the differences in accumulated benefits that would have accrued to beneficiaries under the actual and modified COLA calculations. For an individual at the end of 2017 who had been a beneficiary for 5-years (starting in 2013), the modified COLA would have resulted in benefits that are 4.5% higher than the actual COLA while the benefits to an individual who had been a beneficiary for 10 years (starting in 2008) are 10.5% higher under the modified COLA calculation. Finally, benefits would have been 2.7% higher for a individual who had been a beneficiary starting in 2002 under the modified COLA calculation versus the actual COLAs. To put these in differences in perspective, for a 70-year old individual that retired in 2016 the modified COLA would have resulted in a monthly benefit that is $167 greater than the actual benefit paid to that individual. In terms of hypothetical costs to the Social Security system, Table XII shows that using the modified COLA to adjust benefits from 2003 to 2016 would have increased total benefit payments by approximately $24.2 billion (in constant 2017 dollars).

Furthermore, Novy-Marx and Rauh (2011) and Novy-Marx and Rauh (2014) note that

[21] The annual cost-of-living adjustments are reported at `https://www.ssa.gov/OACT/COLA/colaseries.html`. Technically, our modified CPI is based on CPI-U, but the difference between CPI-U and CPI-W is very small.

relatively small changes in COLA calculations, such as the ones reported here, can have large effects on pension liabilities. For example, in a study of state and local government pension plans, Novy-Marx and Rauh (2011) note that a 1% reduction in COLAs could reduce total public pension liabilities between 9 to 11% or between $280 billion and $470 billion in accumulated benefit obligations (ABO) for the 116 state-sponsored pension funds included in their study. Thus, assuming a linear relationship, if our 5-year estimate of 4.5% for the difference in COLAs persisted, state and local government ABO would be potentially $2.1 trillion higher with our modified index.[22]

B. Real Personal Consumption Expenditures and Gross Domestic Products

The modification to the PCE price index has a direct impact on the calculation of real PCE. The BEA calculates real PCE by deflating the nominal PCE by the PCE price index. In estimating the nominal PCE, BEA mainly uses the decennial Census of Housing, biennial American Housing Survey, Current Population Survey, and Residential Finance Survey (U.S. Bureau of Economic Analysis, 2017). However, the denominator is based on the CPI Housing Survey. Thus, an upward change to the price index has a negative effect on the real value of PCE.[23] Furthermore, the modification to real PCE also affects real GDP because GDP is measured by adding final expenditures (i.e., using the final expenditure approach) in the U.S.[24] This effect is large because PCE accounts for more than 68% of the U.S. GDP in 2015.

To illustrate the impact of our price modification, we deflate the nominal PCE by our modified PCE price index and obtain the modified real PCE and GDP. Specifically, we first

[22] $470 billion times 4.5.

[23] According to U.S. Bureau of Economic Analysis (2017), "rent equals the number of occupied units times the rent per unit" with both the number of housing units and the rent per unit beign estimated from the decennial Census of Housing (COH) and the biennial American Housing Survey (AHS). The COH ad AHS surveys use larger samples than the CPI rent survey. Thus, the numerator reflects housing expenditures based on large samples whereas the denominator is a price index based on a much smaller sample of existing tenants. As a result, our application assumes that any measurement errors in the numerator and denominator are independent and we simply demonstrate the bias that may result from mismeasurement in the denominator.

[24] See U.S. Bureau of Economic Analysis (2015).

compute quarterly percentage change in real PCE by:

$$g_{rpce,t} = g_{npce,t} - i_{modpce,t}, \tag{3}$$

where $g_{rpce,t}$ and $g_{npce,t}$ denote the quarterly percentage change in real and nominal PCE, respectively, and $i_{modpce,t}$ denotes the quarterly percentage change in our modified PCE price index. By using quarterly changes, we calculate the real value in 2009 dollars and the percentage change from a year ago. We then compute the modified real GDP by:

$$r_{gdp,t} = r_{pce,t} + r_{else,t}, \tag{4}$$

where $r_{gdp,t}$, $r_{pce,t}$, and $r_{else,t}$ denote real values in 2009 dollars for GDP, PCE, and other expenditures, respectively.[25] Figure 12 compares the original and modified real PCE. Growth rates from a year ago are almost identical until the Great Recession, but the decrease in real consumption during the recession is much more moderate on the basis of the modified value. The largest quarterly decrease was 1.89% per annum in 2009:I for the modified value whereas it was 4.81% per annum for the original value in 2008:IV. In contrast, the modified real consumption growth is smaller in the current recovery period. The average growth rate after 2009:II is 2.06% per annum for the modified value whereas it is 2.37% per annum for the original value.

Figure 13 shows a qualitatively similar effect of the price modification on real GDP. The modified real GDP decreased by 5.12% per annum whereas the original real GDP decreased by 8.45% per annum in 2008:IV. Thus, any decrease in real GDP was more moderate during the Great Recession. In contrast, the average growth rate after 2009:II is 1.96% per annum

[25] Although the chain-aggregated real expenditures are not additive (Whelan, 2002), errors are negligible in this application. For example, if we calculate real PCE by subtracting non-PCE items from real GDP (i.e., by omitting non-additivity), the error in the annualized quarterly growth rate is only −0.0093%. We have also confirmed that the average difference in the annualized quarterly percentage change in real GDP is only 0.02% if we use Contributions to Percent Change in Real Gross Domestic Product (NIPA Table 1.5.2) as suggested by BEA.

for the modified value whereas it is 2.17% per annum for the original value. As a result, our analysis indicating the CPI inflation over this period of 2.4% per year combined with average real growth of 2.0% suggests that the U.S. economy may be experiencing a period of 'stagflation'. Thus, the lower economic growth and higher inflation may explain the consistent negative consumer sentiment and political uncertainty seen during the economic expansion following the Great Recession (e.g., Bloom, 2014).

VI. Conclusion

Housing rent is the most important component of price indexes (16% of PCE and 33% of CPI). However, the CPI rent index has several important shortcomings. These include the omission of rent changes between leases, smoothing, and lags. We develop a new investor-based net rent income index that has several advantages. The NRI is based on market prices, it reflects both new and existing leases, it is updated monthly, and is consistent with the RRI of Ambrose, Coulson, and Yoshida (2015).

Using the modified price indexes, we find that the NRI-core price indexes significantly decreased (i.e., deflation) during the Great Recession. In addition, due to a very rapid and constant increase in housing rent since 2010, the modified inflation rates were significantly higher than the traditional rates. In fact, the NRI-core CPI indicates that annual inflation rates were constantly higher than 5%. The NRI-core PCE indicates that annual inflation rates were approximately 3% whereas the traditional core PCE indicates constant deflation. Finally, we offer two applications that demonstrate the economic significance of our estimates by examining the effect on cost-of-living adjustments and measurement of GDP.

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	CPI			PCE		
	Shelter	Core	Shelter in Core CPI	Housing	Core	Housing in Core PCE
	(1)	(2)	(3)=(1)/(2)	(4)	(5)	(6)=(4)/(5)
1997	0.294	0.777	0.379	0.151	0.865	0.174
1998	0.299	0.783	0.382	0.151	0.874	0.173
1999	0.299	0.777	0.384	0.150	0.875	0.172
2000	0.299	0.771	0.388	0.149	0.873	0.170
2001	0.312	0.791	0.394	0.153	0.874	0.175
2002	0.314	0.787	0.398	0.153	0.880	0.174
2003	0.325	0.785	0.414	0.152	0.877	0.173
2004	0.323	0.777	0.416	0.150	0.875	0.172
2005	0.319	0.774	0.412	0.152	0.870	0.174
2006	0.324	0.774	0.419	0.152	0.869	0.175
2007	0.323	0.765	0.422	0.152	0.867	0.175
2008	0.329	0.777	0.423	0.154	0.862	0.179
2009	0.319	0.777	0.411	0.162	0.871	0.186
2010	0.316	0.772	0.410	0.158	0.868	0.182
2011	0.312	0.760	0.410	0.155	0.864	0.180
2012	0.313	0.761	0.412	0.154	0.867	0.178
2013	0.317	0.771	0.411	0.154	0.868	0.177
2014	0.323	0.777	0.416	0.154	0.872	0.176
2015	0.328	0.792	0.414	0.155	0.883	0.175
2016	0.333	0.793	0.420	0.158	0.890	0.177
2017	0.333	0.793	0.420	0.158	0.891	0.177

This table shows the relative importance of Shelter in the all-item and core CPI (columns (1) and (3)) and Housing in the all-item and core PCE price index (columns (4) and (6)). The relative importance for CPI is available at: `http://www.bls.gov/cpi/cpiriar.htm`. For the PCE, we follow U.S. Bureau of Economic Analysis (2012) and use current-dollar PCE expenditures as the relative importance weights. The weight in 2017 is based on the 11-month data for PCE and extrapolated from 2016 for CPI.

Table I: Relative Importance of Housing in Price Indexes

	CPI Shelter		PCE Housing	
	Rent of Primary Residence	Owners' Equivalent Rent	Rental of Tenant-Occupied Housing	Imputed Rental of Owner-Occupied Housing
1997	0.234	0.687	0.237	0.750
1998	0.234	0.686	0.234	0.754
1999	0.236	0.685	0.230	0.758
2000	0.237	0.685	0.226	0.761
2001	0.206	0.707	0.223	0.764
2002	0.206	0.709	0.220	0.767
2003	0.189	0.720	0.211	0.776
2004	0.190	0.717	0.206	0.780
2005	0.183	0.735	0.201	0.784
2006	0.183	0.735	0.202	0.783
2007	0.179	0.742	0.213	0.772
2008	0.181	0.743	0.218	0.768
2009	0.187	0.789	0.226	0.760
2010	0.187	0.788	0.231	0.755
2011	0.208	0.768	0.242	0.743
2012	0.209	0.767	0.245	0.742
2013	0.220	0.755	0.242	0.744
2014	0.221	0.753	0.246	0.740
2015	0.236	0.739	0.248	0.739
2016	0.236	0.738	0.257	0.732
2017	0.236	0.738	0.258	0.731

This table shows the proportions of tenant- and owner-occupied housing in CPI shelter and PCE Housing. The relative importance for CPI is available at: `http://www.bls.gov/cpi/cpiriar.htm`. For the PCE, we follow U.S. Bureau of Economic Analysis (2012) and use current-dollar PCE expenditures as the relative importance weights. The weight in 2017 is based on the 11-month data for PCE and extrapolated from 2016 for CPI.

Table II: Components of CPI Shelter and PCE Housing

Number of lags (n)	F	Adjusted R-squared
0	2.74	0.04
1	10.54	0.21
2	27.45	0.42
3	71.00	0.65
4	183.72	0.83
5	291.30	0.89
6	177.88	0.83
7	65.47	0.64
8	26.71	0.41

This table shows the F-statistic and the adjusted R-squared of a regression: $g_{PCE,t} = \alpha + \beta g_{RRI,t-n} + \varepsilon$, where $g_{PCE,t}$ is the percentage change from a year ago in the PCE rent for tenant-occupied housing, $g_{RRI,t-n}$ is the n-quarter lagged percentage change from a year ago in the Repeat Rent Index, and ε is the error term. The number of observations is 38 quarters for all specifications.

Table III: Lags in the PCE Rent Index

	(A)	(B)	(C)	(D)
(A) Net Rent Index	1			
(B) Repeat Rent Index	0.858	1		
(C) PCE Rent (5-quarter lead)	0.884	0.950	1	
(D) PCE Rent (Contemporaneous)	0.512	0.255	0.340	1

This table shows the pairwise correlation coefficient between percentage changes from a year ago in alternative rent indexes. The coefficients are calculated based on 33 quarters between 2002:I-2010:I. The Net Rent Index reflects the average net rent for both new and existing tenants, the Repeat Rent Index reflects the gross rent for new tenants (i.e., marginal rents), and the PCE Rent reflects the gross rent for the existing tenants (i.e., inframarginal rents).

Table IV: Correlation Coefficients Between Alternative Rent Indexes

VARIABLES	Data Period	2001:II-2010:I Mean	S.D.
Net Rent Index	2001:II-2017:III	-0.315	2.335
PCE Rent	1959:II-2017:III	0.743	0.333
Repeat Rent Index	2000:I-2010:I	-0.112	1.394
Marginal Rent Index	2001:II-2017:III	-0.112	1.394

This table shows the mean and variance of quarterly percentage change in alternative rent indexes over 36 quarters between 2001:II and 2010:I. The Net Rent Index reflects the average net rent for both new and existing tenants, the PCE Rent for tenant-occupied housing mainly reflects the gross rent for the existing tenants (i.e., inframarginal rents), and the Repeat Rent Index reflects the gross rent for new tenants (i.e., marginal rents). The Marginal Rent Index is an adjusted Net Rent Index with mean and variance matched with those of the Repeat Rent Index.

Table V: Mean and Variance of Rent Indexes

DEPENDENT VARIABLE: Monthly change in the 13-month lead PCE Rent	
D (Post Great Recession)	-0.0360
	(0.0244)
Net Rent Index	0.0862
	(0.0256)
Net Rent Index ×	0.00325
D (Post Great Recession)	(0.0320)
Constant	0.232
	(0.0209)
Observations	187

This table shows the result of regressions of the monthly percentage change in the 13-month lead PCE rent on the monthly percentage change in the Net Rent Index. The number of lags is chosen to maximize the F-statistic of the regression. The data period is between 2001:4-2016:10. D (Post Great Recession) denotes a dummy variable that takes the value of one after the Great Recession: 2009:7-2016:10. The Newey-West heteroskedasticity and autocorrelation corrected standard errors (12-month lags) are in parentheses.

Table VI: Relation between the Net Rent Index and the 13-month lead in PCE Rent

Variable	N	Mean	S.D.	Min.	Max.
Net Rent Index	66	0.77 %	2.16 %	-6.45 %	5.11 %
Vacancy-Adjusted NRI	66	0.75 %	2.08 %	-5.93 %	5.22 %
p-value of equality		0.77	0.78		

This table shows the summary statistics of the quarterly percentage change in the Net Rent Index and the Vacancy-Adjusted Net Rent Index. The Vacancy-Adjusted Net Rent Index is calculated as: Net Rent Index/$(1 - \text{Vacancy})$. The p-value is the result of the t-test of equal means and the F-test of equal variance.

Table VII: The Effect of Vacancy Rate

	Net Rent Index	Vacancy-Adjusted NRI	Vacancy Rate
Net Rent Index	1		
Vacancy-Adjusted NRI	0.985	1	
Vacancy Rate	-0.557	-0.547	1

This table shows the correlation coefficients between vacancy rates and the quarterly percentage change in Net Rent Index and Vacancy-Adjusted Net Rent Index. Vacancy-Adjusted Net Rent Index is calculated as: Net Rent Index/$(1 - \text{Vacancy})$. The p-value is the result of the t-test of equal means and the F-test of equal variance.

Table VIII: Correlation Coefficients between Vacancy Rates and NRI

	Recession	Expansion	Recession	Expansion	Total
From:	2001:3	2001:12	2007:12	2009:7	
To:	2001:11	2007:11	2009:6	2017:11	
All-Item CPI	1.192	2.877	1.199	1.692	2.052
	(3.294)	(3.479)	(7.859)	(2.462)	(3.707)
Modified CPI	1.261	2.410	-2.089	2.385	1.924
	(4.198)	(3.815)	(8.201)	(2.623)	(4.136)
Difference	0.0690	-0.467	-3.288	0.692	-0.128
	(2.427)	(1.276)	(1.543)	(0.918)	(1.663)
All-Item PCE	0.878	2.455	1.090	1.499	1.780
	(2.662)	(2.294)	(5.202)	(1.704)	(2.513)
Modified PCE	0.822	2.235	-0.597	1.825	1.702
	(2.171)	(2.384)	(5.473)	(1.777)	(2.671)
Difference	-0.0556	-0.221	-1.686	0.326	-0.0772
	(1.133)	(0.570)	(0.816)	(0.459)	(0.815)
Core CPI	2.740	2.047	1.890	1.744	1.907
	(1.179)	(0.991)	(1.000)	(0.873)	(0.959)
Modified	2.827	1.449	-2.343	2.637	1.744
Core CPI	(2.951)	(1.652)	(2.139)	(1.448)	(2.197)
Difference	0.0872	-0.599	-4.233	0.893	-0.163
	(3.068)	(1.641)	(1.984)	(1.183)	(2.138)
Core PCE	1.694	1.946	1.507	1.530	1.684
	(4.191)	(0.839)	(1.004)	(0.795)	(1.148)
Modified	1.632	1.694	-0.437	1.903	1.595
Core PCE	(3.708)	(1.072)	(1.476)	(0.986)	(1.423)
Difference	-0.0621	-0.253	-1.944	0.373	-0.0897
	(1.293)	(0.653)	(0.929)	(0.527)	(0.935)
Observations	8	72	19	101	200

This table shows the average annualized monthly inflation rates for four NBER expansionary/recessionary periods. A negative difference indicates that the modified inflation rate is lower than the original inflation rate. Standard deviations are in parentheses.

Table IX: Average Inflation Rates by Business Cycle

Variable	Lags	Consumer Price Index				Personal Consumer Expenditure Price Index			
		All-Item		Core		All-Item		Core	
		Original	Modified	Original	Modified	Original	Modified	Original	Modified
Price	0	0.005	0.958	0.000	1.000	0.000	0.861	0.000	0.996
Index	1	0.032	0.900	0.000	1.000	0.003	0.737	0.000	0.995
(Level)	2	0.055	0.858	0.000	1.000	0.008	0.656	0.000	0.993
	3	0.071	0.829	0.000	0.997	0.014	0.601	0.001	0.991
	4	0.085	0.804	0.000	0.996	0.020	0.556	0.002	0.988
	5	0.096	0.782	0.000	0.996	0.026	0.522	0.005	0.985
	6	0.104	0.766	0.000	0.995	0.032	0.498	0.011	0.982
First	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difference	1	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
	2	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
	3	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
	4	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

This table shows the result of the Phillips-Perron unit root test. The reported numbers are the MacKinnon approximate p-value of failing to reject the null hypothesis that the variable contains a unit root. The number of lags is for the Newey-West heteroscedasticity and autocorrelation robust standard errors.

Table X: Phillips-Perron Unit Root Test

Starting Year and number of years in beneficiary status	Accumulated Cola Modified	Actual
2013 (5-years)	8.6%	4.0%
2008 (10-years)	21.8%	11.3%
2002 (16-years)	38.5%	35.8%

This table shows cumulative benefit in 2017 accruing to a beneficiary under the actual and modified COLAs. The number in parentheses indicates the total years in beneficiary status.

Table XI: Accumulative Benefit Increases from COLAs as of 2017 (in percent)

Year	Beneficiaries (millions)	Benefit Payments (billion)	Modified COLA (billion) (A)	Actual COLA (billion) (B)	Difference (A)-(B)	Cumulative Difference (billion in 2017)	Inflation Factor[a]
2003	46.4	$453.8	$456.9	$463.3	-$6.4	-$8.6	0.748
2004	47	$470.8	$477.9	$483.5	-$5.6	-$15.8	0.768
2005	47.7	$493.3	$504.7	$513.5	-$8.8	-$26.9	0.794
2006	48.4	$520.7	$545.5	$537.9	$7.6	-$17.6	0.820
2007	49.1	$546.2	$552.1	$558.8	-$6.7	-$25.6	0.843
2008	49.9	$585.0	$600.9	$618.9	-$18.0	-$46.1	0.875
2009	50.9	$615.4	$631.9	$615.4	$16.5	-$27.2	0.872
2010	52.5	$675.5	$675.5	$675.5	$0.0	-$27.2	0.886
2011	54	$701.6	$712.0	$726.9	-$14.9	-$43.5	0.914
2012	55.4	$725.1	$759.4	$737.4	$22.0	-$19.9	0.933
2013	56.8	$774.8	$796.4	$786.4	$10.0	-$9.4	0.947
2014	58	$812.3	$828.3	$826.1	$2.2	-$7.2	0.962
2015	59	$848.5	$874.2	$848.5	$25.7	$19.5	0.963
2016	60	$886.3	$893.5	$889.0	$4.6	$24.2	0.976

This table shows yearly change in actual total Social Security benefit payments and total benefits based on the modified COLA calculation.

Table XII: Year Over Year Change to Average Monthly Benefits from COLA Adjustments

[a] Source: `http://liberalarts.oregonstate.edu/spp/polisci/faculty-staff/robert-sahr/inflation-conversion-factors-years-1774-estimated-2024-dollars-recent-years/individual-year-conversion-factor-table-0`

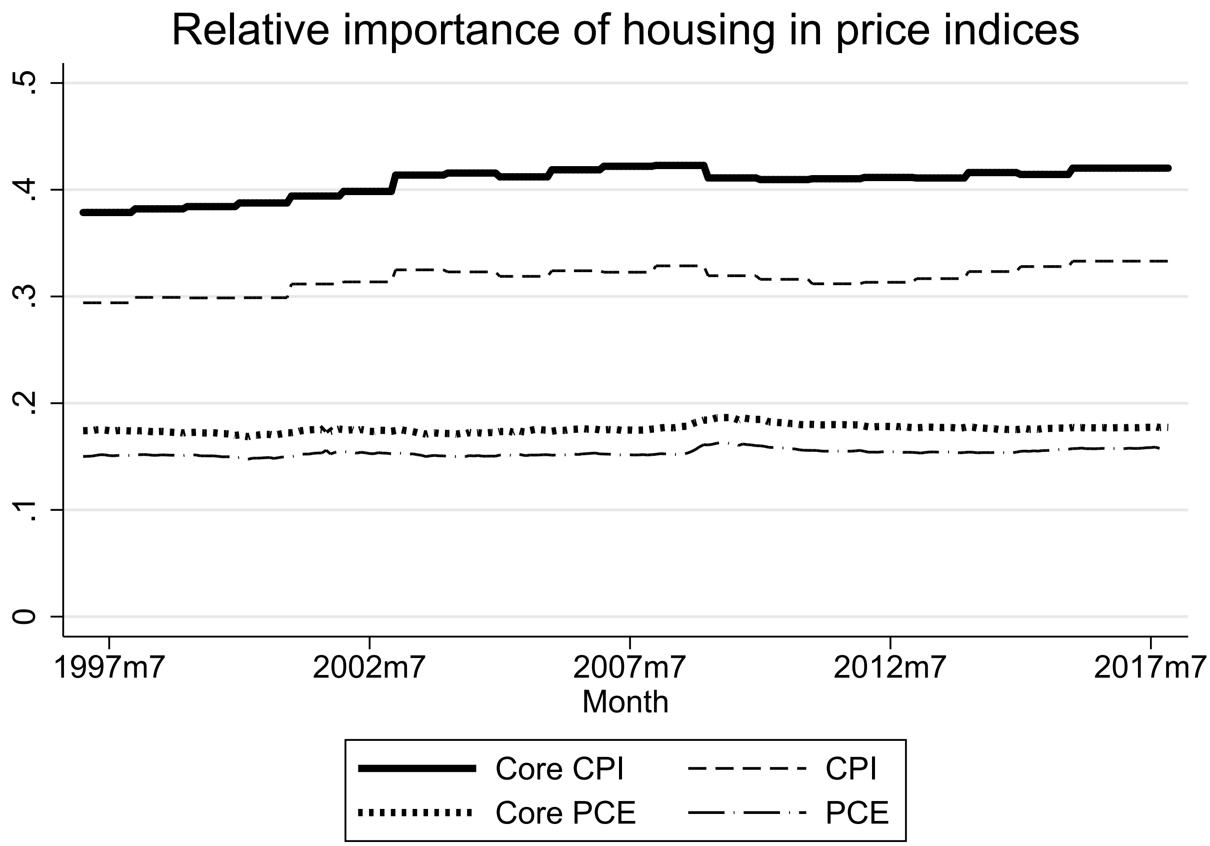


Figure 1: Relative Importance of Housing in Price Indices

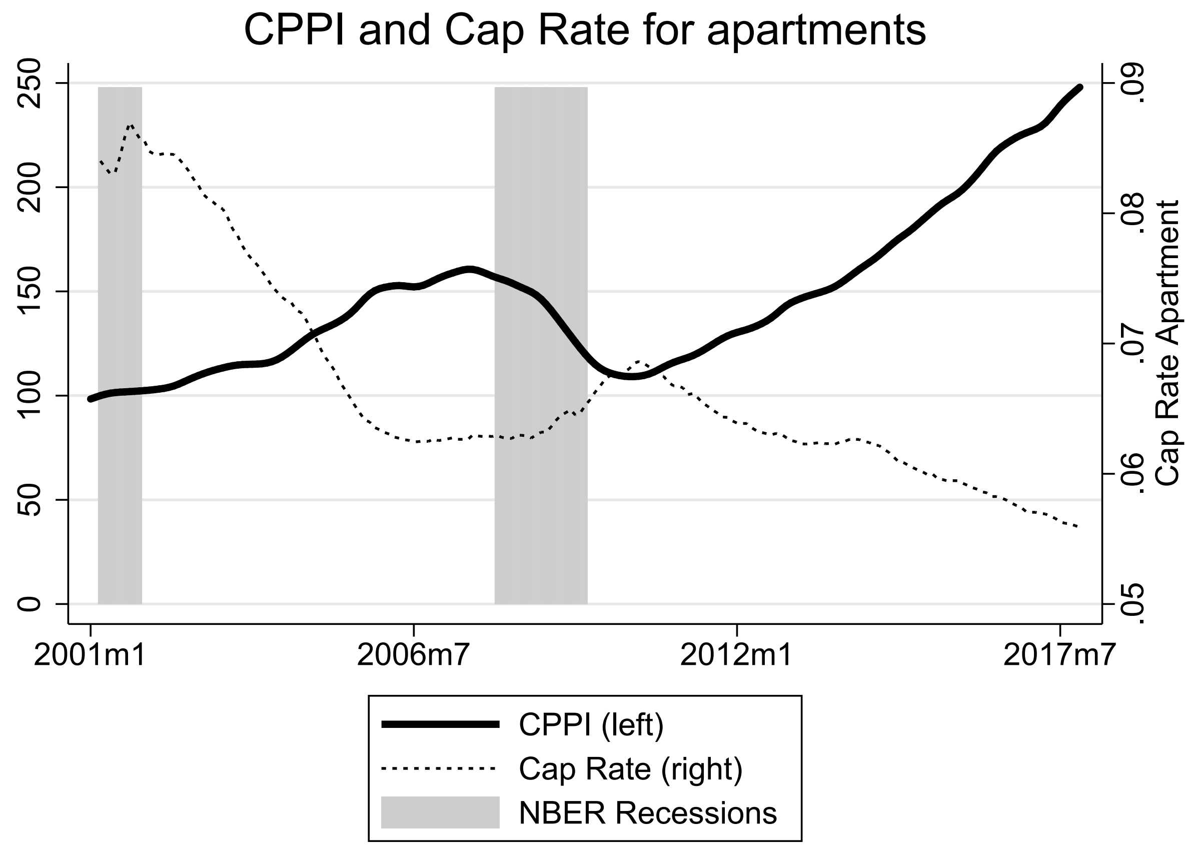
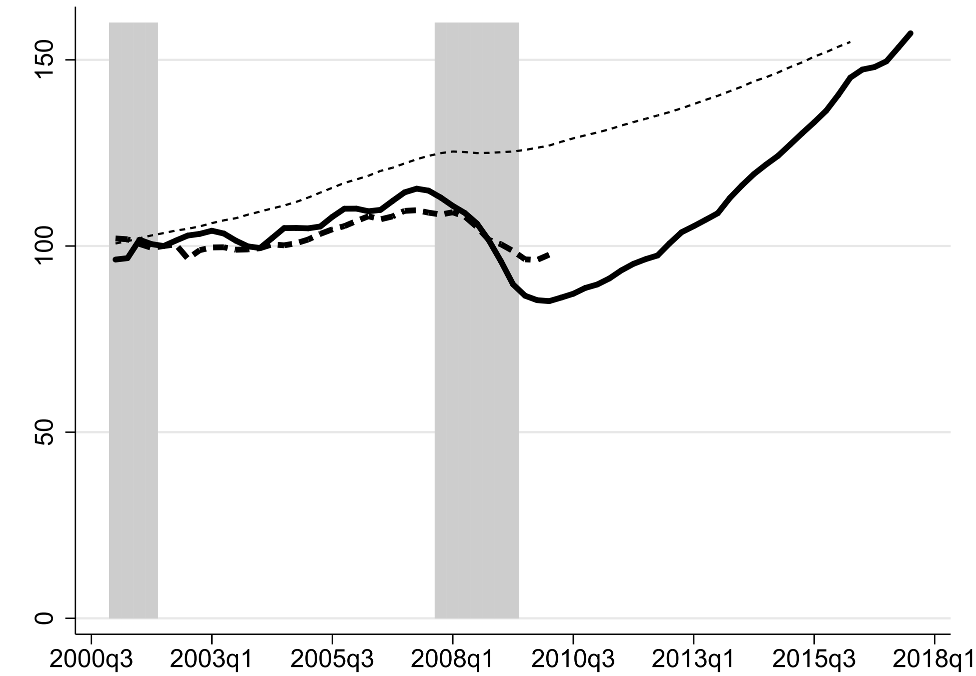
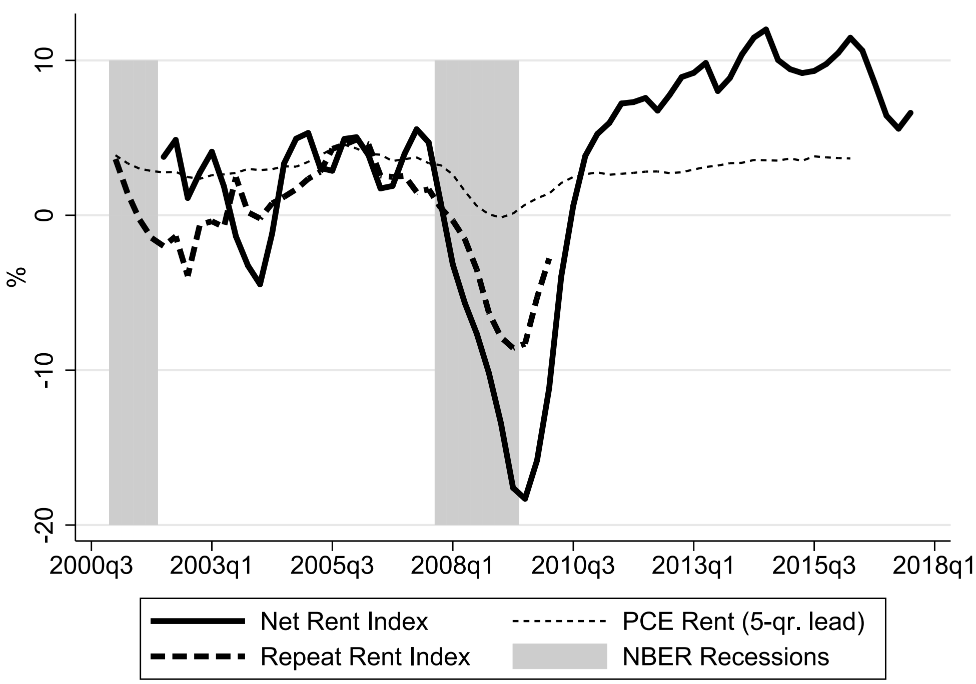


Figure 2: CPPI and Capitalization Rate for Apartments

This figure depicts the Moody's/RCA Commercial Property Price Index (CPPI) for apartments and RCA capitalization (cap) rate. The CPPI is a monthly repeat sale index. Both indexes are based on the Real Capital Analytics commercial real estate transaction data.



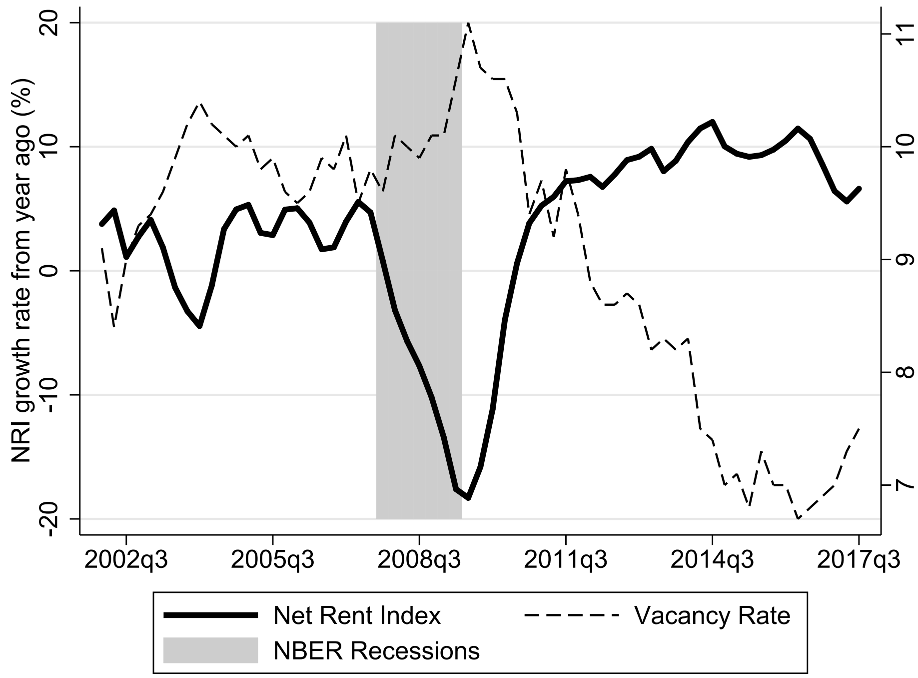
(a) Index Level



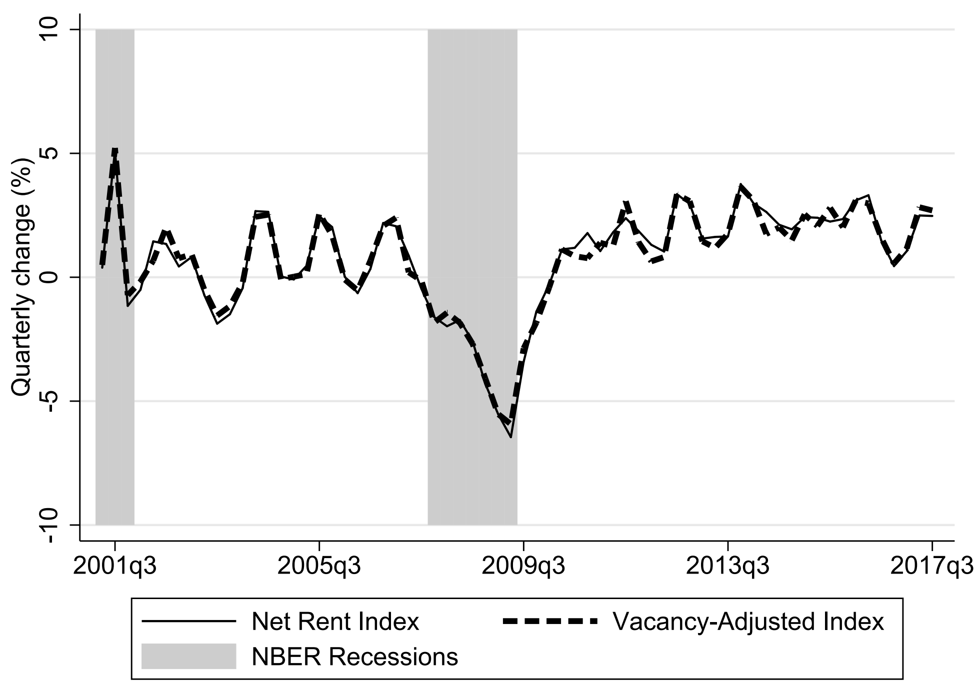
(b) Percentage Change from a Year Ago

Figure 3: Comparison of Net Rent Index, PCE Rent, and Repeat Rent Index

The Net Rent Index is a quality-adjusted average net rent index based on Moody's/RCA CPPI and RCA capitalization rates. The PCE rent is based on the BLS rent index. The Repeat Rent Index is developed by Ambrose, Coulson, and Yoshida (2015)



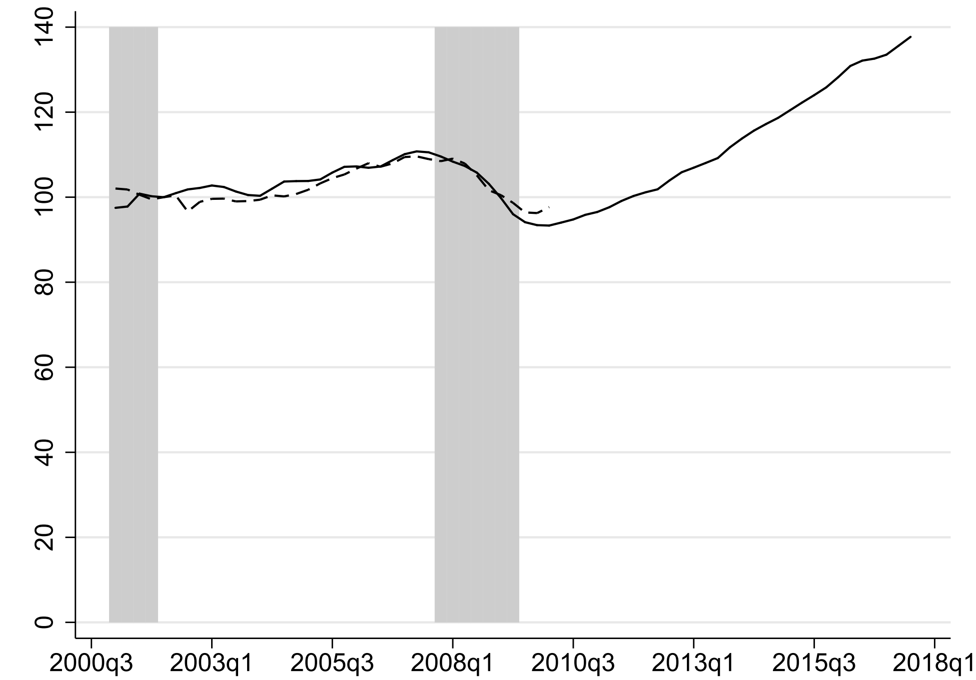
(a) Net Rent Index and Vacancy Rate



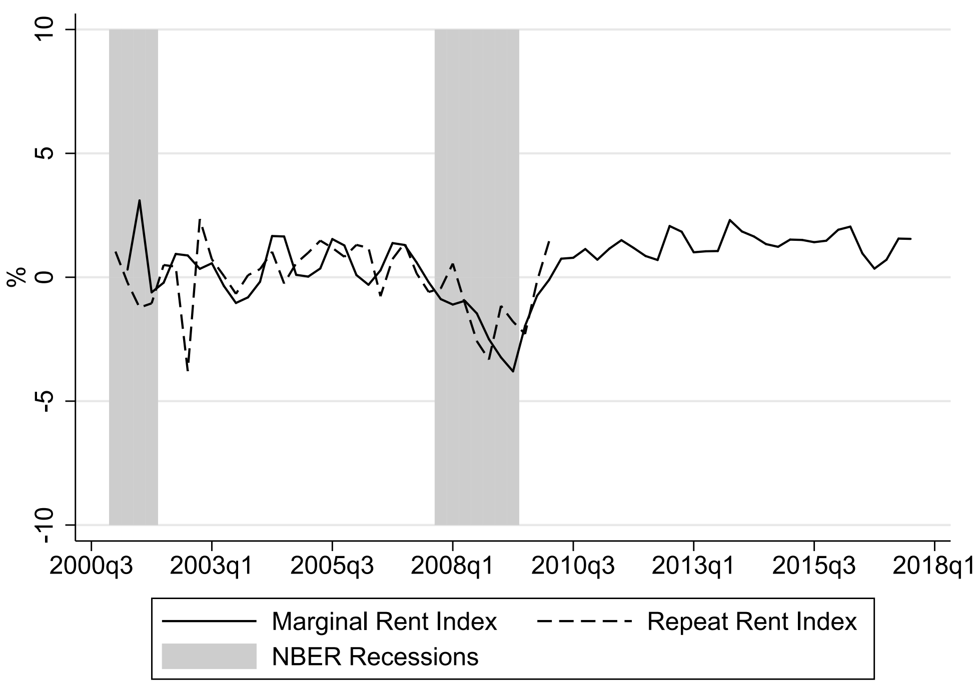
(b) Vacancy-Adjusted Net Rent Index

Figure 4: The Effect of Vacancy Rate

This figure depicts the percentage change from a year ago in NRI and the national rental vacancy rate published by the U.S. Bureau of the Census. The Vacancy-Adjusted Net Rent Index is calculated by dividing NRI by 1 minus vacancy rates.



(a) Index Level



(b) Quarterly percentage change

Figure 5: Repeat Rent Index and Marginal Rent Index

The Marginal Rent Index (MRI) is based on the Net Rent Index and has the same mean and standard deviation of quarterly growth rates as the RRI. The monthly percentage change in the MRI ($g_{mri,t}$) is estimated as: $g_{mri,t} = -0.03927653 + 0.4850342 \times g_{snri,t}$, where $g_{snri,t}$ is the standardized monthly percentage change in the NRI with zero mean and unit sample variance.

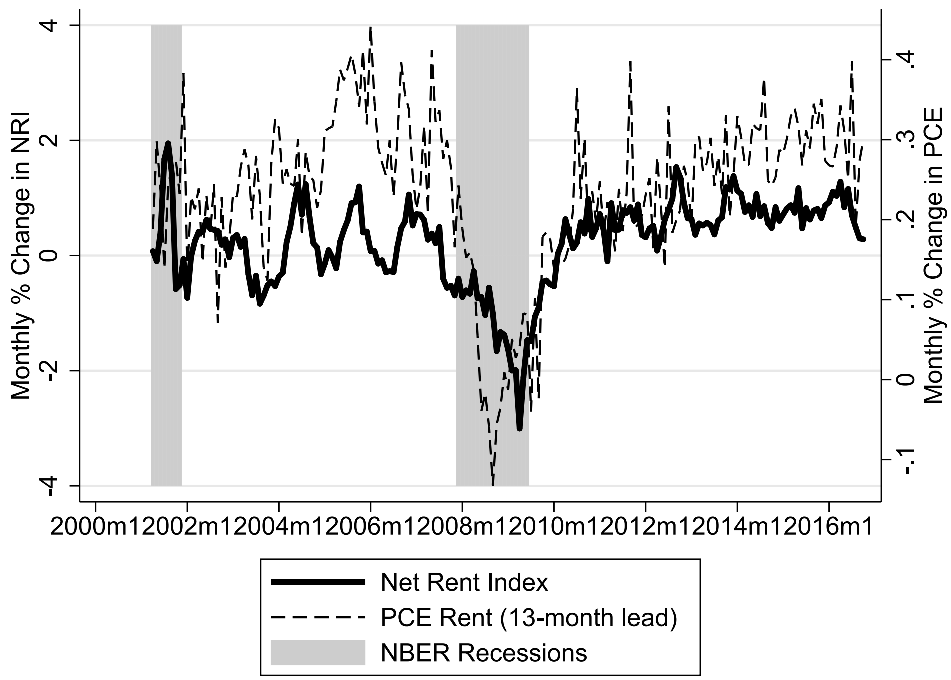
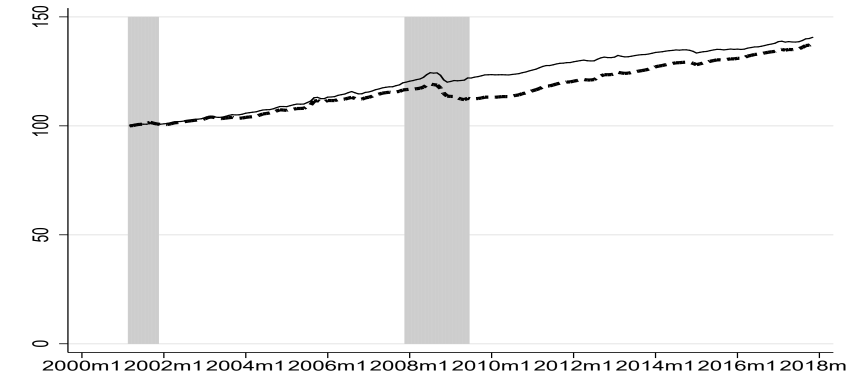
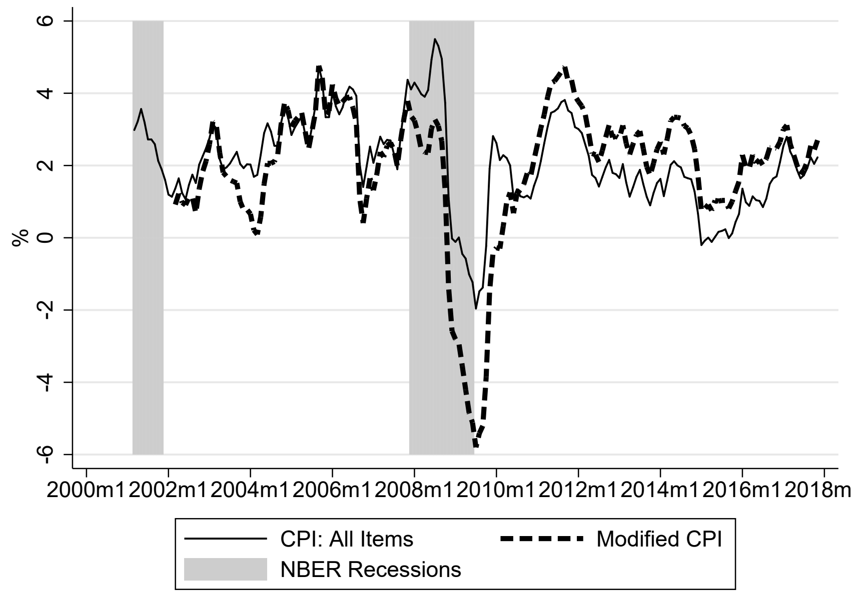


Figure 6: Relation between Net Rent Index and the 13-Month Lead PCE Rent

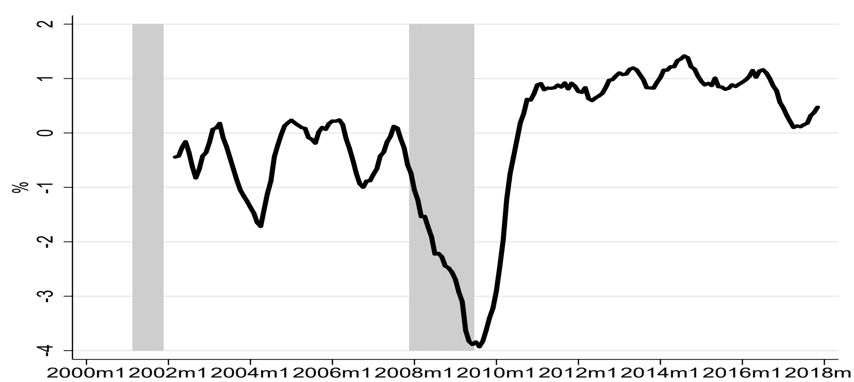
This figure depicts monthly percentage changes in the 13-month lead PCE rent and the Net Rent Index. The number of lags is chosen to maximize the correlation coefficient.



(a) Index Level

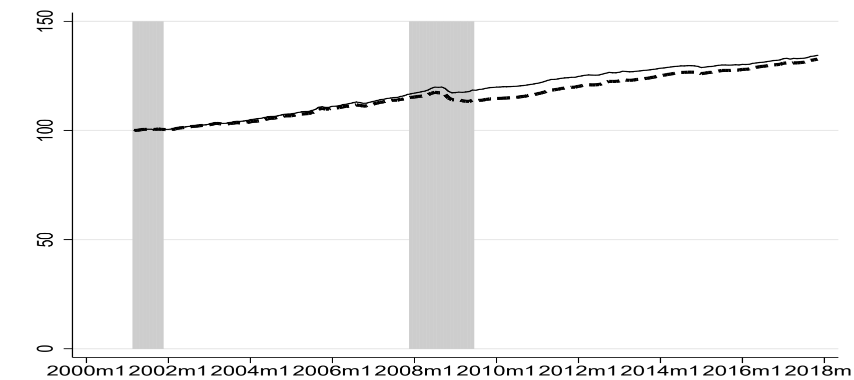


(b) Percentage change from a Year Ago

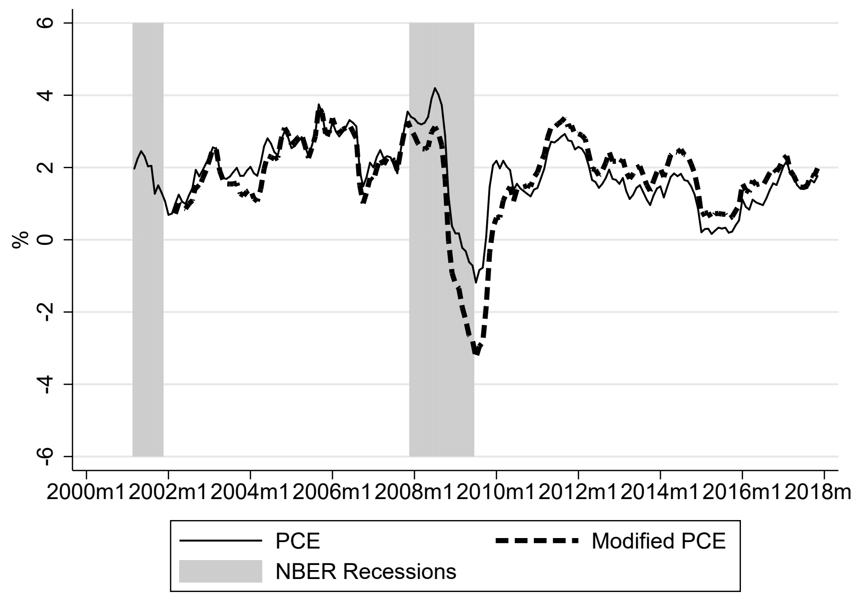


(c) Difference between the Modified and Original CPI

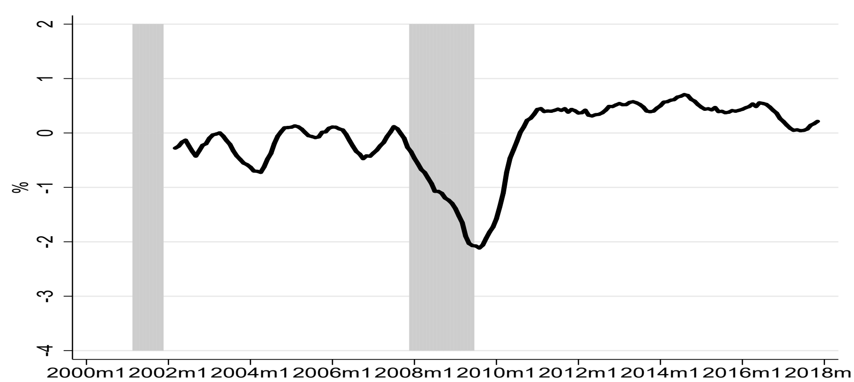
Figure 7: All-Item CPI and Modified CPI



(a) Index Level

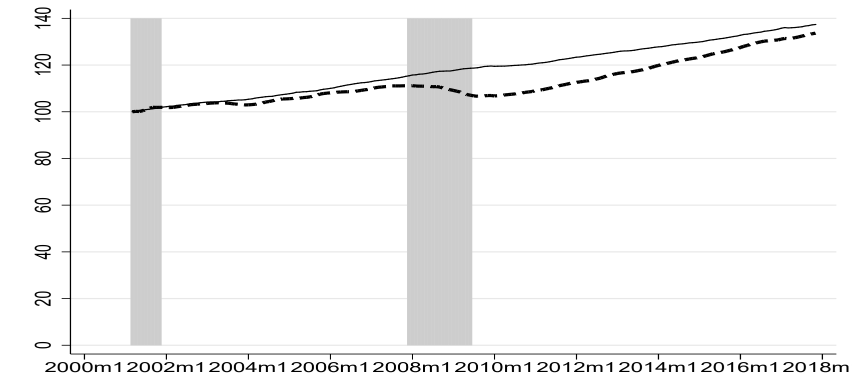


(b) Percentage change from a Year Ago

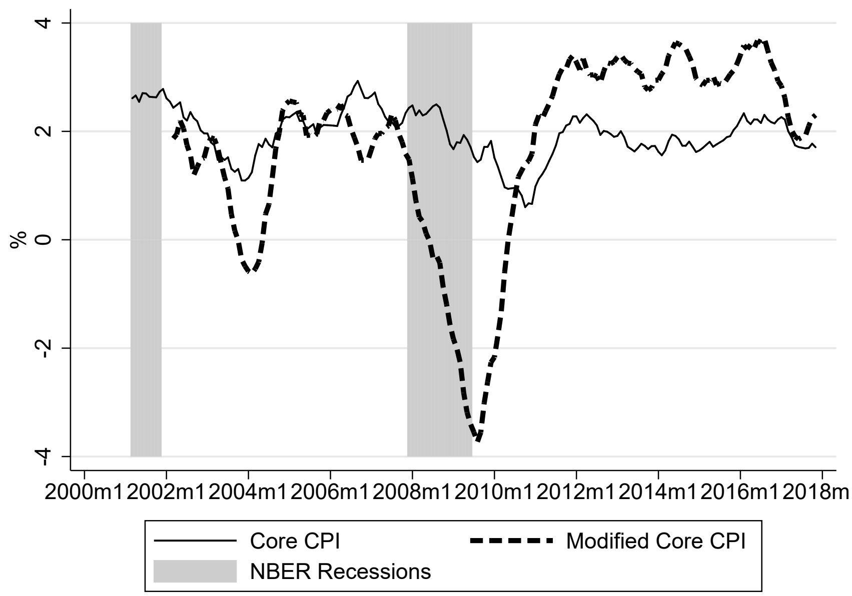


(c) Difference between the Modified and Original PCE

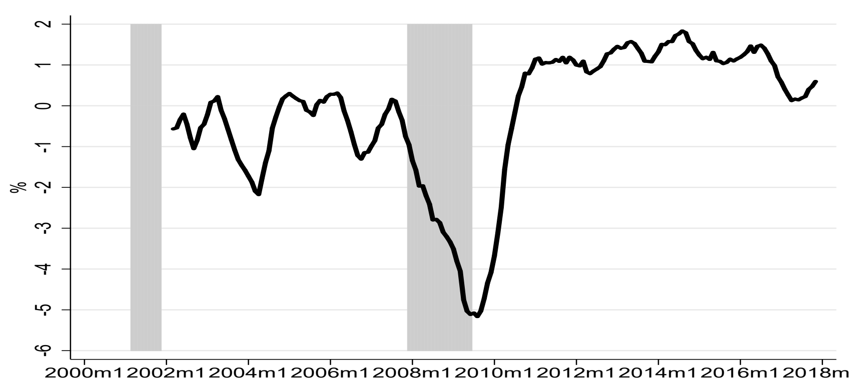
Figure 8: All-Item PCE and Modified PCE Price



(a) Index Level

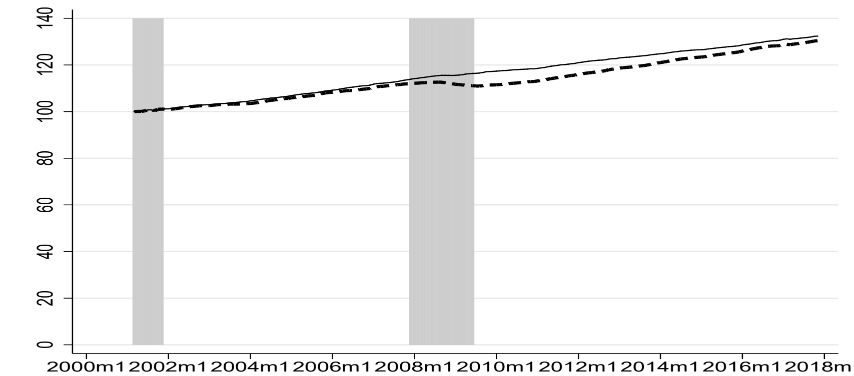


(b) Percentage change from a Year Ago

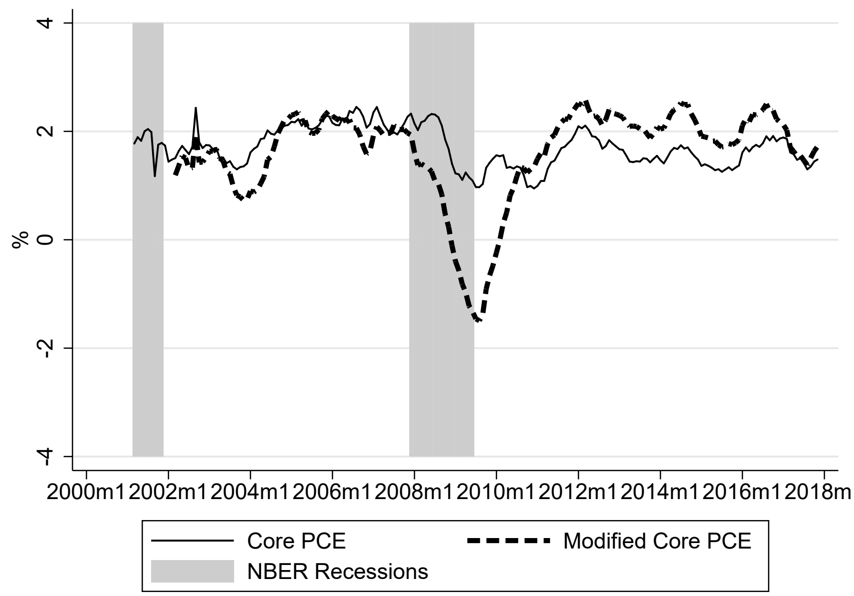


(c) Difference between the Modified and Original Core CPI

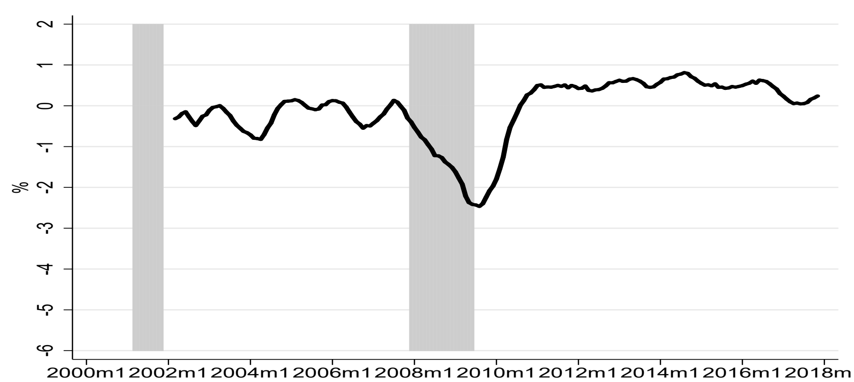
Figure 9: Core CPI and Modified Core CPI



(a) Index Level



(b) Percentage change from a Year Ago



(c) Difference between the Modified and Original Core PCE

Figure 10: Core PCE and Modified Core PCE Price

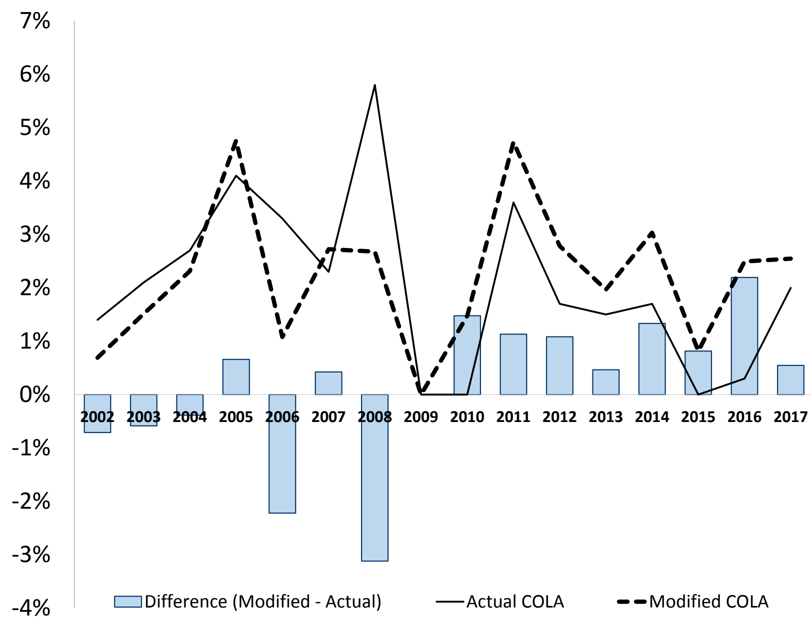
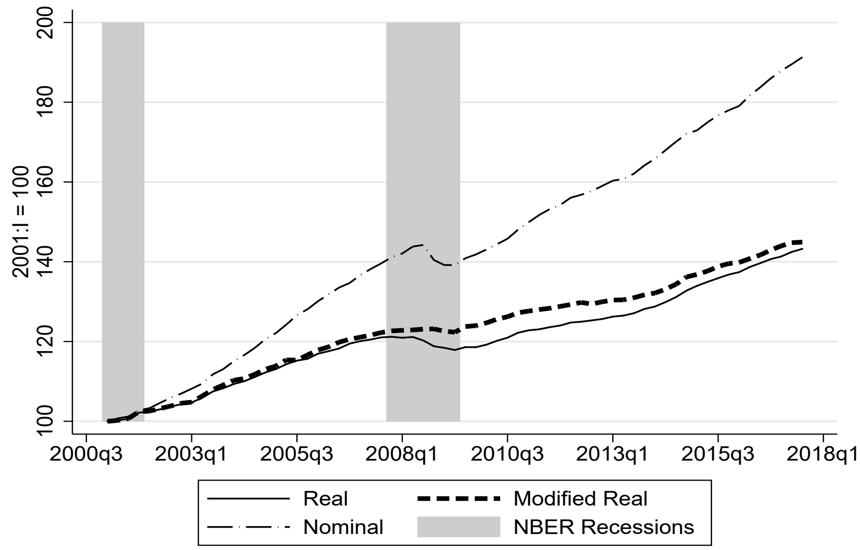
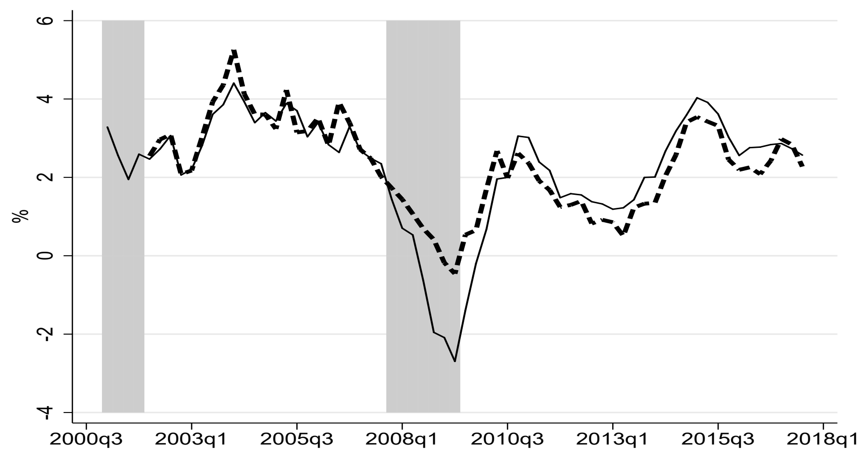


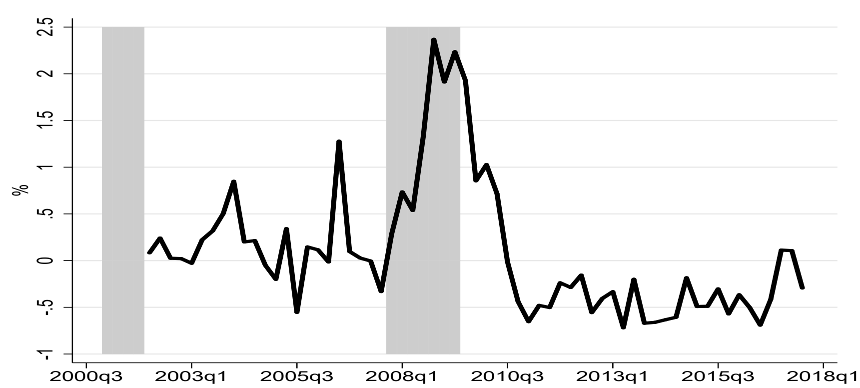
Figure 11: Annual Social Security Cost of Living Increases (COLAs): Actual versus modified



(a) Personal Consumption Expenditures

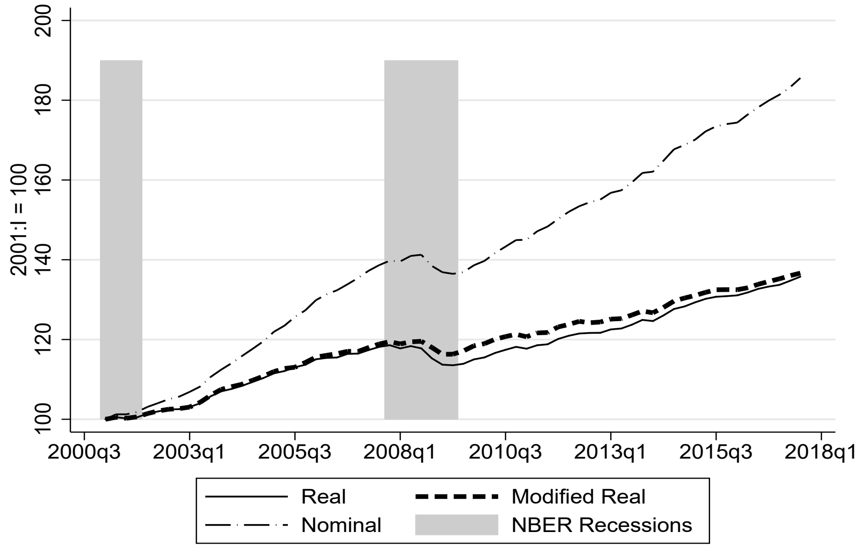


(b) Percentage change from a Year Ago

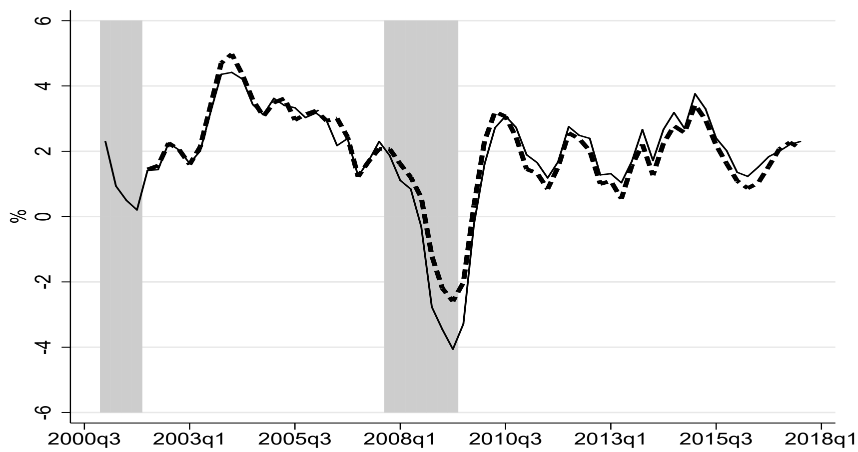


(c) Difference (Modified - Original)

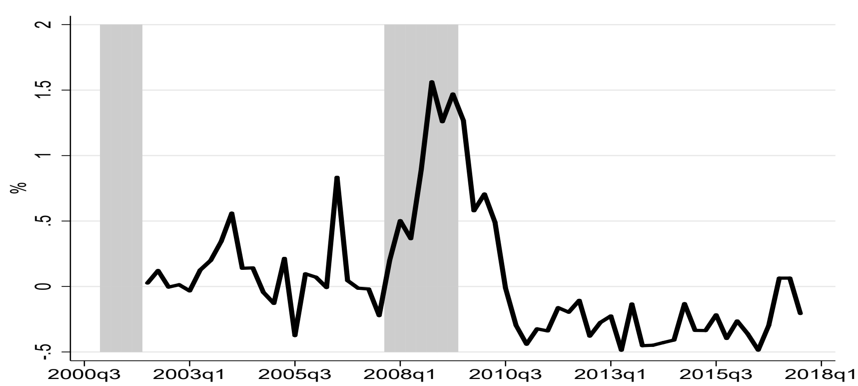
Figure 12: Original and Modified Real Personal Consumption Expenditures



(a) Gross Domestic Product



(b) Percentage change from a Year Ago



(c) Difference (Modified - Original)

Figure 13: Original and Modified Real Gross Domestic Product

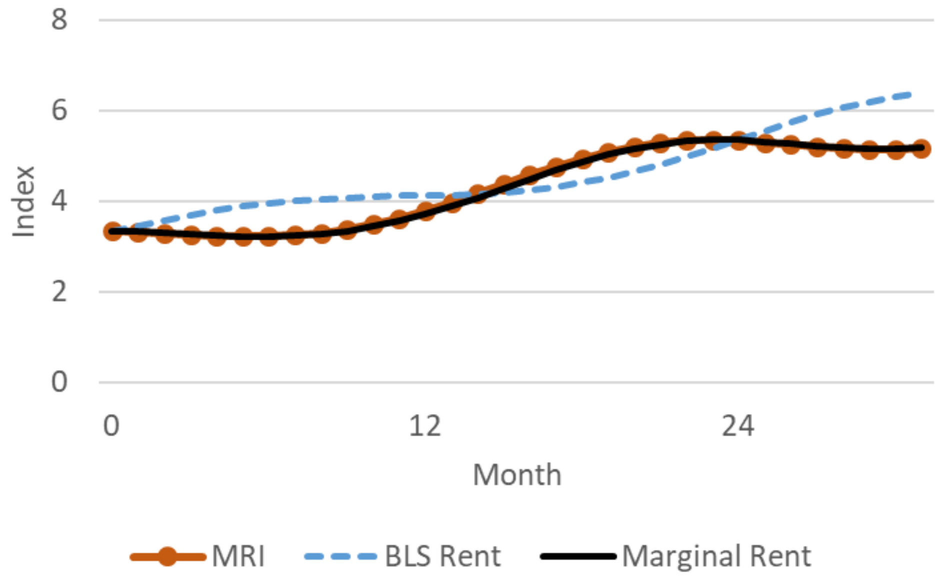
Appendix A Timeliness of MRI based on investors' projected NOI: A numerical illustration

In this appendix, we illustrate that the Marginal Rent Index (MRI) can timely replicate the low-frequency dynamics of the true marginal rent process when the index is based on investor's projected NOI. We also demonstrate that the rent index constructed by the BLS method lags marginal rents approximately by one year.

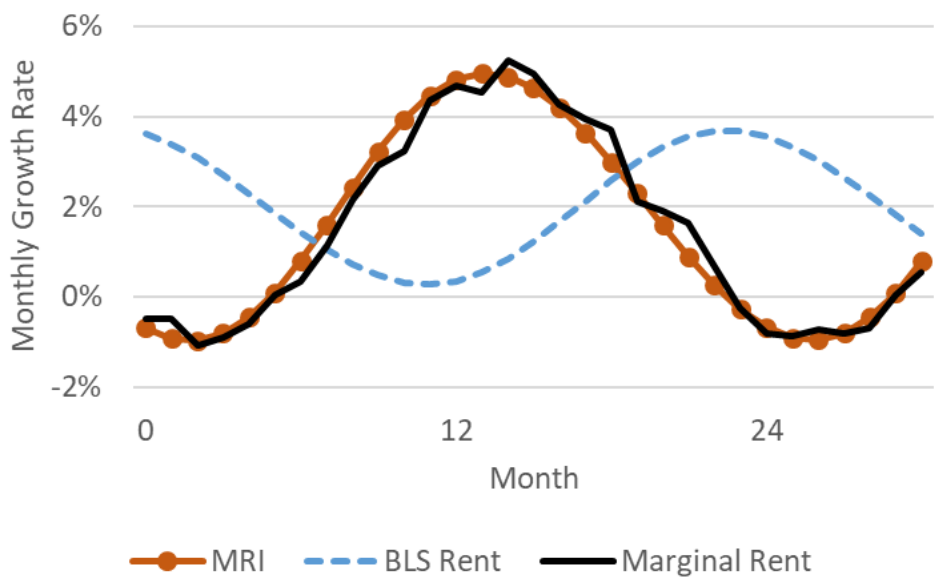
Assumptions

1. The lease term is one year for all leases.
2. The contract date is the beginning the month, and contract months are evenly distributed throughout the year.
3. The monthly growth rate of gross marginal rents has a low-frequency cycle component and disturbances:
$$g_{MR} = a + b \sin\left(\frac{\pi m}{12}\right) + \varepsilon, \tag{A.1}$$
where g_{MR} denotes the monthly growth rate of gross marginal rents, $a = 0.02$ denotes the long-run mean growth rate, $b = 0.03$ denotes a scale parameter for the low-frequency cycle component, m denotes the model month, and ε denotes the mean-zero normal disturbance term with standard deviation of 0.002.
4. The net operating income (NOI) is calculated by subtracting operating expenses from total annual gross rental income for both new and existing leases. Operating expenses grow constantly at 2% and do not fluctuate with cycles. On average, operating expenses are 42% of gross income.
5. When reporting cap rates, investors make the 12-month projection of NOI for the coming year, which is the source information for our Net Rent Index.
6. Investors on average make the correct projection of the low-frequency cycle component of the gross marginal rent process although they do not know disturbances.
7. The Marginal Rent Index (MRI) is constructed by matching the mean and standard deviation of growth rates for NOI and marginal rents.
8. The BLS rent index is constructed by the sixth root of the past six-month growth rate for the average gross rents.

The following figure depicts the simulation result. The MRI approximately mimics the low-frequency cycle component of the marginal rent process. In contrast, the BLS rent index is smoother and lags the marginal rent process approximately by one year.



(a) Index Level



(b) Monthly Growth Rate

Figure 14: Simulated Rent Indexes

This figure illustrates the simulated indexes when the growth rate process gross marginal rents is composed of a low-frequency cycle and disturbances. The Marginal Rent Index (MRI) is based on investors' average projected NOI for the coming year. The MRI is constructed by changing the mean and the standard deviation of NOI growth to match with marginal rent growth. Without shifting the timing, MRI correctly captures the dynamics of marginal rents whereas the BLS rent index lags approximately by one year.