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ABSTRACT

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Until the end of 1977, the method used in the U.S. consumer price index (CPI) to measure rent inflation tended to omit rent increases when units had a change of tenants or were vacant. Since such units typically had more rapid increases in rents than average units, this response bias biased inflation estimates downward. Beginning in 1978, the Bureau of Labor Statistics (BLS) implemented a series of methodological changes that reduced response bias but substantial bias remained until 1985. We set up a model of response bias, parameterize it, and test it using a BLS microdata set for rents. We conclude that from 1940 to 1985 the CPI inflation rate for rent most likely was understated by 1.4 percentage points annually in U.S. data. We construct an improved rental inflation series for 1940 to 2000; at the starting point in 1940, the revised index is 54 percent as large as the official CPI.

JEL Classifications:C81, C82, E31,O47, R21, R31

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THE CPI FOR RENTS:
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I. Introduction and Overview

This paper constructs a revised estimate of the U.S. consumer price index (CPI) for tenant rents from 1940 to 2000. Until the end of 1977, the method used by the U.S. Bureau of Labor Statistics (BLS) in the CPI to measure rent inflation tended to omit rent increases when units had a change of tenant or were vacant. Since such units typically had more rapid increases in rents than average units, this response bias biased inflation estimates downward. Even after 1977, substantial biases remained in the index until 1985.

We set up a model of response bias and parametrize the model from a variety of sources. We then check the parameterization by using a CPI rental microdata set from 1988 to 1992, a period when the biases had been almost entirely corrected and we can directly measure BLS adjustments. The model implies that the BLS measures of rental inflation were subject to a severe form of response bias from 1942 to 1985 that resulted in an understatement of the inflation rate for housing services of 1.2 percentage points annually from 1942 to 1985. The BLS has estimated that aging bias also affected these data by about 0.4 percentage point annually, so that in total the average annual understatement of rental inflation amounted to 1.6 percentage points annually during this period.

Most studies of price mismeasurement have concentrated on upward biases in inflation measures (Boskin et al., 1996; Price Statistics Review Committee, 1961). This paper discusses a case of downward bias in inflation measurement in an important part of the U.S. economy: tenant rents. While one component of response bias, vacancy nonresponse, was analyzed in Rivers and Sommers (1983) and corrected by the BLS in 1985, this is the first paper to discuss the response bias due to loss of tenant contact. Neither component of response bias was mentioned in recent discussions of historical CPI bias such as Stewart and Reed (1999) and Boskin et al.(1996), nor was it mentioned in Moulton's (1997) review of rental inflation biases.

Before 1978 the data used to estimate rental inflation in the U.S. Consumer Price Index (CPI) suffered from two forms of downward bias: nonresponse bias and aging bias. Nonresponse bias, the more important of the two and the focus of this paper, has its source in rental turnover. When a tenant stops occupying a rental unit in the CPI survey, its rent may not be reported either because (1) the unit is vacant or (2) the new tenant is not contacted or does not respond. Since tenant changes normally coincide with rental price increases, ignoring nonrespondents may result in a large downward bias. Aging bias, the second form of bias, occurs when the quality of the average rental unit deteriorates over time because of inadequate maintenance. If the rental price of a unit remains constant and its quality deteriorates, its quality-adjusted rent has risen. Therefore, rental inflation data unadjusted for aging may be downwardly biased. The bias due to aging was not addressed by the BLS until 1988.

From the mid-1940s forward, researchers at the BLS and in academia suspected that the CPI rental index was downwardly biased (Humes and Schiro, 1948, 1949; Weston, 1972; and Ozanne, 1981). However, the source of the bias – whether it was due to response problems, aging bias, or omission of new units – remained murky. More recently, papers by Crone et al. (2004) and Gordon and vanGoethem (2003) have also suggested such a bias in historical data.

After 1978 the portion of nonresponse bias due to vacancies was still reflected in the CPI, and a new downward bias was introduced by the adoption of a formula that depended on the tenant's recall of the previous month's rent (tenants tended to underreport these rental price increases). Following Rivers and Sommers, the bias due to vacancies was removed in 1985, as was most of recall bias. The last vestige of recall bias was eliminated in 1994.

Census Bureau measures of rent illuminate the possible magnitude of the nonresponse bias in the rental CPI. The decennial Census of Housing and the biennial American Housing Survey show that median gross rent rose 2.4 percentage points faster than the CPI for rent between 1940 and 1985 (Table 1).[2] Taking the CPI data at face value, this implies that the

[2] Gross rents include utilities such as gas and electric and heating, whether included in the contract rent or not. This is a better basis for comparison because the proportion of utilities included in contract rents has fallen over time.

quality of the median rental unit increased 2.4 percent a year during this period. By comparison, from 1930 to 1940 and from 1985 to 2001, median gross rents rose less than half a percentage point faster than the CPI rent index, implying a substantially lower increase in quality.[3] We believe this anomaly is primarily due to the downward nonresponse bias in the CPI rental inflation rate.

Uncovering this case of inflation understatement is significant for two reasons. First, housing services are an important component of consumption and its source, residential assets, a large component of wealth. Their historical growth rates have important implications for past living standards. If rental inflation is biased downward, then housing services growth is biased upward. We find that real housing services a half century ago were almost twice as large as current historical statistics argue. The level of real PCE as a whole in 1942 is about 9 percent higher and its annual growth rate from 1942 to 1985 is 0.2 percentage point lower; real GDP is 5 percent higher and its growth rate 0.1 percentage point lower. Second, the Bureau of Labor Statistics has long argued that it has been more evenhanded about inflation than its critics have claimed--i.e., its errors have not always resulted in an upward bias in inflation. Moreover, this is a case where the BLS removed an important source of bias without any prod from outside criticism.

Section II of this paper reviews the history of steps taken by the BLS to correct biases in the CPI rental series. Section III models nonresponse bias in the rental CPI and parameterizes the model based on data from the Census Bureau and BLS microdata on rental increases. The parameterized model is used to estimate the bias in rental inflation from 1942 to 1977 and tested with BLS CPI microdata for 1988-92. Section IV discusses two additional issues, recall bias and sampling frequency. Section V presents our revised rental price index and some additional data on prices and output to suggest that this new estimate is reasonable. Section VI concludes the paper.

[3]Prior to 1940, the BLS directly interviewed landlords and real estate managers rather than tenants, and it believes the problem of nonresponse bias was not a major one.

II. History of Changes in BLS Methodology to Correct for Bias in the CPI for Rent

Prior to 1942, nonresponse was not a significant problem in the BLS rental survey because price inspectors obtained their data from the files of real estate agents and large-property owners. This system had the advantage of avoiding a dependence on tenant response. The price inspector could directly compare current rents with past rents, even if the tenant had changed. If a unit was vacant, a comparable unit could often be found from the books.

In 1942, the BLS inadvertently created a substantial downward response bias in its procedure for sampling rents.[4] It shifted from asking landlords and managers for rental information to obtaining that information from tenants, and usually missed the rent increase that occurred when tenants moved out. Between 1953 and 1994, the BLS largely corrected nonresponse and other biases in the CPI in six steps. The six steps were:

(1) a reduction in the frequency of collection of prices from quarterly to semiannually in 1953 (less frequent collections decreased recording of unchanged rents relative to rent increases);

(2) the replacement of mail surveys in 1964 by personal visits and telephone interviews, increasing somewhat the rate of response at units where tenants had moved out;

(3) a major change in sampling procedures and methodology in January 1978 that resulted in a significant reduction of the number of nonrespondents, in large part because information was obtained from landlords and managers (although nonresponse from vacant units remained a problem), but introduced a recall bias in the estimate;

(4) an adjustment to the rental component of the CPI in January 1985 that corrected for vacancy-related nonresponse bias and had the effect of eliminating much of the recall bias;

(5) an aging-bias adjustment in January 1988, based on Randolph's (1988a and 1988b)

[4] All sample surveys suffer from nonresponse, i.e., incomplete returns from some part of the targeted sample. Pakes (2003), for example, discusses a response bias in the case of PCs where model exit results in omitting prices that decline, creating an upward bias. In our case, response bias results in omitting prices that rise.

estimates (correction for aging bias is the only part of this history to which this paper contributes no new analysis);

(6) the elimination in January 1994 of the recall formula that had introduced recall bias in 1978.[5]

Quarterly mail survey, 1942. Starting in 1942, as war-time rent controls took effect, price inspectors were instructed to obtain rents directly from tenants, which increased the potential for nonresponse bias in the rental-price series.[6] Some 37,000 units in 34 cities were sampled. Following an initial interview to elicit cooperation and gather data about the unit, the tenant was mailed a rent questionnaire quarterly. One study of responses from March to September 1947 found that approximately 50 percent of the initial mail questionnaires were completed by the tenant. An additional 20 percent were returned on follow-up, but the nonresponse rate was 30 percent -- 5 percent were returned unable to locate and 25 percent were not returned (Humes and Schiro, 1949). In a mail system, when a tenant moved, the mail questionnaire, having been addressed to a previous occupant, would be forwarded or returned to the sender. The BLS rental price inspector would have to ascertain who the new occupant was and solicit his or her cooperation with a new interview and start over again. Such a process would almost invariably miss the rent increases associated with a change of tenants.

Semiannual rent collection, 1953. In 1953, without any fanfare, it appears that the rate of rental collection was changed from quarterly to semiannually, but we have only indirect evidence of the change. Collection of mortgage rate and other price information on the costs of owner-occupied housing was instituted in the 1953 CPI revision, so this was a period in which major changes did occur to the housing index (Lamale, 1956). And when the 1964 revision was announced, it included information that implied that rent collection had become semiannual at

[5] While the 1994 change in the formula for aggregating rental data eliminated the recall bias, it effectively introduced a three-month lag in the reporting of rental inflation.

[6] It was feared that rental increases that evaded or violated rent control laws might not be accurately reported by real estate agents or landlords. These fears were not groundless; Humes and Schiro (1949) report that BLS rents reported twice as many price increases as were authorized in a period in 1947.

some previous date.

Personal visits and telephone surveys, 1964. The method of survey by mail was deemed unsatisfactory because of the large number of nonrespondents. In 1964 the BLS instituted a system of using part-time agents to collect rental data by personal visit or telephone. The sample size remained at about forty thousand. No substitution was permitted for units whose prices were not obtained. Solicitation by telephone would have the same problem of missing new tenants as the mail survey; instead of receiving the mail back, the price inspector would find that the telephone number was no longer in service or had been changed. Again the price inspector would have to begin over with a new solicitation. Personal visits might have a greater likelihood of response from a new tenant, but the new tenant, even if successfully contacted, would be less likely to cooperate than a tenant who has already agreed to participate. The institution of personal visits does not appear to have greatly reduced response bias; overlap data showed that the new procedures introduced in 1964 did not raise the measured rate of inflation but actually reduced it.[7] Nevertheless, we believe that there was some improvement at this time in reaching new tenants.

Reducing response bias and introducing recall bias, 1978. Beginning in 1978, a new survey method was instituted to ensure that the sampling of rental units was as thorough as possible and, in particular, to capture rent increases when the tenant moved. The number of rental units surveyed was cut by more than half to 18,000. Data were also obtained on the length of occupancy of new tenants. Price inspectors could choose to interview the landlord or manager instead of the tenant and typically did so. Price inspectors were to reinterview the tenant, manager, or owner of the unit every six months.

In addition, a new method was instituted for using the rental data obtained from the interview. First, respondents were asked the level of last month's rent as well as the current

[7] From January to June 1964 the data were collected using both the old and the new survey methods. During this period, there was very little difference between the two series, and by the end, the revised index for rent was 107.8 (on a basis of 1957-59 = 100) compared with the unrevised index of 107.9. So the revised index rose more slowly. The June 1963 rent index was 106.8, so the rental CPI at this time was rising at an annual rate of about 1 percent.

month's rent. Then two comparisons were made: the six-month price increase using the previous interview and the one-month price increase. The rental index was computed using both the one-month change and the six-month change, weighted to minimize fluctuations.[8] Defining I(t) as the level of the index at month t, and Rt,t-k as the change in rent from k months ago, the rental formula was:

$$I(t) = 0.65\ R_{t,t-1}\ I(t-1) + 0.35\ R_{t,t-6}\ I(t-6). \qquad (1)$$

This formula, known as the recall formula, permitted the CPI measure to reflect current inflation fully and immediately, while minimizing noise. Unfortunately, use of the formula introduced recall bias, because respondents often failed to remember increases in rent that had occurred in the previous month. This recall problem applied to both tenants and to landlords and managers. The reason for this recall problem is unclear, but it appears possible that while the BLS does not consider a rent to have increased until the unit is rented, the respondents considered the rent to have increased when the new asking rent was raised. The respondents' view would mean that the rental increase occurred while the unit was vacant. In any case, the average change from the previous month as recorded was substantially less than one-sixth the average change from six months prior.

Vacancy bias and recall bias correction, 1985. When the BLS corrected nonresponse bias for units that had changed tenants in 1978, it did so by raising response rates rather than through a deliberate bias adjustment. In analyzing CPI rental data in the wake of the 1978 procedural changes, it discovered that nonresponse bias was a problem at vacant units. Vacancy mattered because the BLS has been hesitant to rely on rental asking prices and treats vacant units as lacking a price and therefore requiring an imputation. This is in contrast to the BLS practice

[8] That is, the coefficients weighting the six-month change and the one-month change were chosen to minimize the decided seasonal patterns that emerge if you use only six-month data ((I(t)=Rt,t-6 I(t-6)) or only one-month data (I(t) = Rt,t-1 I(t-1).

[11] The Rivers and Sommers data divide tenants into those with five month or less occupancy and six months or more. It may thus underestimate the proportion of new tenants included in the data, as tenants with more than five months but less than six months occupancy may be in the six months or more category.

for prices other than rents, where transactions are frequent enough so that the BLS feels confident in relying on the asking price, for example, the marked or posted price of a retail item.

Rivers and Sommers (1983) highlighted the fact that units that had changed hands experienced higher rates of inflation (Table 3). In their study, Rivers and Sommers divided their sample into continuing tenants (those with six or more months of occupancy, 81.2 percent of the sample) and new tenants (18.8 percent).[11] This breakdown was consistent with a turnover rate of about 40 percent annually and, therefore, suggested that the new BLS survey procedures did succeed in capturing almost all new tenants. They further noted that rents changed nearly twice as often when units changed hands, which meant that more first-month changes were omitted when vacancies were omitted. They surmised that if they imputed rents for vacancies and also imputed one-month changes in rents, they could reduce both vacancy bias and recall bias. In their simulations, they eliminated vacancy bias and eliminated four-fifths of recall bias.

In light of the Rivers and Sommers analysis, the BLS decided to impute rents for vacant units using the six-month rent changes for similar units that had turned over for which data were available. This vacancy-imputation methodology was implemented in January 1985. Our analysis of the Rivers and Sommers findings implies that correcting the vacancy response bias alone would have raised the rental inflation rate by 8.7 percent. In addition, the partial correction of recall bias raised the inflation rate by 7.6 percent. Combining these two, introducing the vacancy imputation methodology appears to have raised measured rental inflation by 17.0 percent.[13]

[13] This is in line with BLS estimates. In the January 1985 CPI Detailed Report, the BLS estimated that the vacancy imputation adjustment would raise the inflation rate for rents by less than 0.1 percentage point a month. From December 1982 to December 1983, the rental rate rose at an annual rate of 4.8 percent, and from December 1983 to December 1984, at 5.8 percent. Thus 0.1 percent a month could represent 20 to 25 percent of the measured inflation rate, depending on the base against which it was calculated. Vacancy imputation left only a small recall bias, 1.8 percent, to be finally eliminated in 1994.

Aging bias correction, 1988. Aging bias refers to the underestimation of rental increases because of the systematic deterioration in the quality of housing services provided by a rental unit as it ages. Historically, the BLS has adjusted the change in rent for *observed* quality changes, such as the addition of a room. But prior to 1988 the agency did not correct for the systematic deterioration in quality associated with aging. If a unit deteriorates systematically with age, a constant rent over the six-month period implies an increase in rent on a quality-adjusted basis. In 1988 the BLS began adjusting the measure of rental inflation for aging based on the estimates of Randolph (1988a and 1988b).

There are two potential problems in a hedonic regression approach to estimating the effect of physical deterioration on rents. The first is the so-called vintage effect. This effect arises when there are unmeasured quality characteristics other than physical deterioration associated with age but not other measured characteristics of the residence. For example, the more extensive use of insulation in houses built after the 1970s would raise the unmeasured quality of those units. On the other hand, units built prior to World War II and still occupied may represent the highest quality units built in those years if lower quality units built at that time are no longer in use. These so-called vintage effects make it difficult to get an accurate estimate of the effect of physical deterioration on rent. The second problem in estimating the effect of aging on rent is that units of different types (e.g., apartments versus detached houses) may deteriorate at different rates.

In his 1988 article William Randolph (1988b) took steps to solve both of these problems in estimating the effect of systematic physical deterioration on rents. Randolph argued that including a sufficient number of housing and neighborhood characteristics in a hedonic equation would render the remaining vintage effect minimal.[14] He included housing characteristics like the presence of a dishwasher or washer/dryer and neighborhood characteristics like the percent of the population with a college education. He also estimated different aging effects depending

[14] Gordon and VanGoethem argue that quality improvements in housing are insufficiently accounted for in Randolphi's methodology.

on the number of rooms in the unit, whether the unit was detached, and whether it was rent controlled. His resulting estimate of the *average* effect of aging on rent was - 0.36 percentage point a year. The BLS has used Randolph's estimating technique, updated over time, to impute the effect of aging to adjust the rent component of the CPI since 1988. Generally speaking, BLS estimates of the average aging effect have changed very little. In our revised measure of rental inflation, we adjust for aging bias before 1988 by adopting Randolph's -0.36 percentage point correction.

Recall bias correction, 1994. The recall bias problem introduced in 1978 was completely resolved in 1994 when the BLS discontinued the use of reported one-month rent increases in estimating rental inflation (Armknecht, et al., 1995). At this time, the rent formula was changed so that the monthly rate of rental inflation was calculated as the sixth root of the average six-month inflation rate. The new formula, while free of downward bias, results in roughly a three-month lag in the reporting of changes in the rental inflation rate.

III. Modelling and Parameterizing the Consequences of Sampling and Response

In this section, we set forth a simple model of the quantitative impact of response bias.We then discuss how we have parameterized the model, using data from a variety of sources, and then we test the parameterization with microdata from the CPI rental survey from 1988 to1992.

Rents in the United States are typically, but by no means always, changed annually when the lease is renewed.[15] More and less frequent adjustment may occur: the lease contract may be for more or less than a year; there may be no lease contract; or the lease contract may provide for rental price changes during its term. But the data indicate that most rent increases occur at

[15] The annual lease is the predominant form for rentals. Data from the U.S. Census Bureau's Property Owners and Managers Survey in 1995 (single-family and multifamily units, excluding data not reported or for rent free units) showed that 44.4 percent of all units had annual leases, 4.0 percent had leases longer than one year, 36.1 percent had leases less than one year, and 15.5 percent had no leases. These facts suggest that while the annual lease is the modal contract under which rental units are occupied, it is by no means universal. Thus the simple model that underlies our work is an approximation. The survey can be found at http://www.census.gov/hhes/www/poms.html.

roughly annual intervals. This fact influences both how the BLS measures rents and the biases that appear in rental price collection.

III. 1 A model of rent collection with nonresponse

Response bias. In this section, we set forth a model that will enable us to quantify the impact of response bias. The model assumes that rental units are subject to annual leases. We assume that in a given month at a given rental unit the log rent increases ($x_{it} > 0$) with probability θ (=1/12). When the rent increases, with probability ρ the tenant leaves the unit.

A complicating issue is that the rate of annual inflation at rental units from which tenants move is, on average, higher than at units of continuing tenants.[16] Let us define the rent increase for continuing tenants as π_{Ct}. Where the tenant moves, the rent increase is larger by some fraction b; for those units, the rent increase is $(1+b)\pi_{Ct}$. Then the rental inflation rate for complete data would be $\pi_t = (1+\rho b)\pi_{Ct}$.[17] We shall assume that vacancies and reoccupied units have the same rate of increase.

Every n months, prices are collected by a BLS price inspector. Response bias is due to the fact that when the tenant moves, the price inspector is less likely to record any price for the unit, either because the unit stands vacant or because of loss of contact with the tenant. Let us call q_M the probability that a unit where the tenant has moved will have a price recorded, and q_C the probability that a unit with a continuing tenant will be recorded, with $q_M < q_C$. The annualized measured rate of inflation (π_t^m) and the complete data rate of inflation (π_t) are then (see Appendix 3 for derivation):

$$\pi_t^m = \frac{1-\rho(1-\frac{q_M}{q_C}(1+b))}{1-n\theta\rho(1-\frac{q_M}{q_C})}\pi_{Ct} \qquad (2)$$

[16] This issue is discussed in Genesove (1999), who argues that landlords and tenants share the ex post surplus of good matches.

[17] We refer to this as the "complete data" rental inflation rate rather than the "true" inflation rate because it is not adjusted for aging bias.

$$\pi_t = (1+\rho b)\pi_{Ct} = \frac{(1+\rho b)(1-n\theta\rho(1-\frac{q_M}{q_C}))}{1-\rho(1-\frac{q_M}{q_C}(1+b))}\pi_t^m \qquad (3)$$

The size of response bias is the coefficient on measured inflation is equation 3. If q_M/q_C is equal to 1, then this coefficient becomes 1, and the measured inflation is the actual inflation rate: response bias is due to obtaining fewer observations from units where tenants have moved than units tenants continue to occupy.

All rents omitted when tenant has moved: If rental prices of units that are vacated, whether reoccupied or not, are not collected, then $q_M = 0$ and the general equation simplifies to

$$\pi_t^m = \frac{(1-\rho)\pi_{Ct}}{1-n\rho\theta}. \qquad (4)$$

If rents are collected annually, $n\theta = 1$, the frequency of sampling would equal the frequency with which prices are changed, and the measured rate of inflation would equal the inflation rate of rents for continuing tenants. Response bias in that case is reduced to the fact that continuing tenants experience lower rates of inflation than new tenants. But with $n\theta < 1$, as the case is with sampling every six months, measured inflation gives too much weight to tenants who are in the portion of the annual cycle in which the rent does not increase.

The complete data rate of inflation would then be:

$$\pi_t = \frac{(1+\rho b)(1-n\theta\rho)}{1-\rho}\pi_t^m.$$

Modelling vacancy nonresponse. If rental prices are collected when a vacated unit has been reoccupied but not when the vacated unit remains vacant at the time of the next price inspection, we need to calculate the rate of reoccupation. We shall assume a constant rate of reoccupation -- for each successive month for a unit whose tenant has left, with probability $1-\alpha$ a new tenant occupies the unit with a year-long lease at a new fixed price, and with probability α the unit remains vacant. For units occupied in a given month, n months later a price increase will have occurred on average at $n\theta$ units; at these units $n\theta(1-\rho)$ of the old tenants remain, $\theta\rho(n-\alpha(1-$

α^n)/(1-α)) new tenants have moved in, and $\rho\theta\alpha(1-\alpha^n)/(1-\alpha)$ units will have become vacant. To simplify notation, define the ratio of these vacant units to those that experienced a price change as $v \equiv \frac{\rho\alpha(1-\alpha^n)}{n(1-\alpha)}$.

If, for a unit whose original tenant has left, the subsequent rental price is collected when the apartment is reoccupied but not when the unit remains vacant, that is, $\frac{q_M}{q_C} = 1 - v/\rho$, then:

$$\pi_t^m = \frac{(1+\rho b - v(1+b))\pi_{Ct}}{1 - v\theta n} \tag{5}$$

$$\pi_t = (1+\rho b)\pi_{Ct} = \frac{1 - v\theta n}{1 - v\frac{1+b}{1+\rho b}}\pi_t^m .$$

According to the model we have developed, the CPI for rents prior to 1978 suffers from a response bias whenever tenant turnover occurs and rental increases are not recorded. Prior to 1978, the measured rate of inflation followed equation 4, plus aging bias. After 1978, the CPI for rents still suffered from nonresponse due to vacancy and followed equation 5, plus recall bias and aging bias. To examine these relationships quantitatively, we need to estimate the turnover rate (ρ), the vacancy rate (α), the higher rate of inflation experienced by units that turn over (b), and the relative sampling rate of units where tenants move (q_M/q_C). We assume that units can turn over only at one-year intervals and that rent increases occur only at this time.

If we had annual data on each of the parameters of the model for the units in the BLS survey, our measure of response bias and our corrections to it would be exact. However, we must derive estimates of the parameters of the model from a variety of data sources and will assume that these estimates apply to the BLS surveyed units.[18]

[18] Below, we check the reasonableness of this assumption by applying the estimates to a BLS microdata set from 1988 to 1992.
[20] The Census period is the previous year and the first three months of the current year. That means that the first quarter is counted twice, a period in which turnover is somewhat lower than during the rest of the year. According to our BLS microdata, 21.6 percent of movers move in during the first quarter of the year; accordingly, we divided this figure by 1.216 to estimate annual movers.

We now turn to estimating the parameters of the response model.

III.2 Estimates of nonresponse model parameters

Turnover rate, $\rho = 0.344$. The annual turnover rate ρ in our model is the percentage of persons who move *out* of rental units in a given year. As far as we know, there are no published estimates of the turnover rate. The American Housing Survey and the Censuses of Housing both have data on recent movers *into* units. Recent movers into units differ from those who move out of units because they include those who have moved into *new* and thus previously unoccupied rental housing. Annual turnover can be obtained by subtracting new rental units from recent movers. The 1970 Census of Housing provides data on renters who moved into their units between the beginning of 1969 and March 1970.[20] Beginning in 1973, the American Housing Survey (AHS)[21] provides data on renters who moved into their units in the past 12 months. To estimate the number of renters who moved into new units, we use the number of multifamily (two or more) units constructed during a given year (some new single-family units are rented and some multifamily units are sold for owner occupation, but over the period 1970-93 these two have roughly canceled out).[22] The estimates are shown, together with the underlying data used in the estimates, in Table 2. For data available from 1970 to 1993, the turnover rate averaged 34.4 percent, varying from 31.1 percent to 37.6 percent, with a standard deviation of 1.86 percentage points.

Rental inflation rate adjustments for units where tenants move, b=.33. Using data from the BLS CPI survey of renters from October 1979 to March 1981, Rivers and Sommers (1983) found that rent increases differed between tenants who had lived in their units less than six months (new tenants) and those who had lived in their units six months or more (continuing tenants). Among those tenants who had a rent increase, new tenants recorded a six-month

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[21] The AHS was known as the Annual Housing Survey from 1973 to 1981, prior to the survey becoming biennial and being renamed the American Housing Survey. We use the new title throughout.

[22] According to the U.S. Census Bureau's American Housing Survey, *Components of Inventory Change, 1980-1993, Pub 8/96*, 95 percent of the multifamily units completed in the same period were rental units. Similar figures apply for 1970 to 1980.

[24] Percents have been converted to log percents. This involves some inaccuracy, as average percents and average log percents differ depending on the variance.

increase averaging 11.40 percent (Table 3, occupancy status five months or less, column 5);[24] continuing tenants had an average increase of 8.56 percent (Table 3, six months or more, column 5). Thus, new tenants experienced a 33 percent higher rate of rental inflation when their rents increased.

The sampling rate of units whose tenants have moved, $q_M/q_C = 0.2$ for 1964-1977. The sampling rate of units whose tenants have moved can be inferred from changes in surveying techniques, overlap data, and estimates for recall bias. For the period before 1964, given the high rate of nonresponse, it seems reasonable that $q_M = 0$, that is, no new tenants were sampled when surveys were conducted by mail. The sampling rate for new tenants increased after 1964 when personal visits were instituted. The BLS changed the interview procedures again in 1978 resulting in virtually complete coverage of occupied units so that the only remaining bias should have been that associated with new tenants. Unfortunately, the BLS unintentionally introduced recall bias in the rental inflation measure at the same time.

For the first six months of 1978 the BLS calculated the rental CPI using both the old and the new formula (Table 4). Our estimate of recall bias for this period, discussed below, is that it was 9.1 percent (in log terms). If we accept this estimate of the recall bias and set $q_M/q_C = 0$ in equation (2), the overlap data should have shown a rental inflation rate that was 25 percent higher using the new formula than the old formula. The actual difference was 10 percent. This implies that the sampling rate of new tenants was $q_M/q_C = 0.2$. Armknecht, Moulton, and Stewart (1995) estimate that the recall bias represented 9 percent of rental inflation, virtually the same as ours.

Monthly vacancy hazard rates, $\alpha = 0.65$. The parameter α is the probability that a vacant unit is not reoccupied in a given month. This monthly hazard rate is needed to determine the likelihood that an apartment that turns over is vacant when it is surveyed. To estimate the monthly hazard we turn to data on vacancy rates by length of vacancy available in the Housing Vacancy Survey (HVS), which is conducted as part of the Bureau of Labor Statistics' Current

Population Survey.[25] The HVS provides information on the proportion of rental vacancies by length of vacancy: units vacant less than six months generally account for 80 percent of units for which the length of vacancy is known. Units vacant less than six months were 5 percent of all rental units from 1970 to 1999, Table 5. In addition, there are units that are rented but not yet occupied. These appear to be about 1 percent of all units. Assuming that 80 percent of these units have been vacant less than six months, we have total vacancies in a six-month period of 5.8 percent.

Using the model, the one-month vacancy rate is $\rho\alpha\theta$, the total vacancy rate is $\rho\alpha\theta/(1-\alpha)$ and the six-month vacancy rate is $\rho\alpha(1-\alpha^6)\theta/(1-\alpha)$. Assuming that ρ=.39, $\theta = 1/12$, if we set $\alpha = .675$, then the percentage of units that are vacant 1 month or less is 1.94 percent, and the percentage of units that are vacant six months or less is 5.39 percent. This matches the data for 1980-2001 tolerably well (Table 5).[26]

Bias correction factors. In Table 6 we summarize the correction factors that arise from our parameters. These are the factors that we will use to construct our new index of rental price inflation. Table 6 gives a chronology of BLS changes in its rental collection methods and our model estimates for the impact of each change. For the entire period of 1942 to 1977 we use the model parameters: higher rate of rental increase, b = 0.33; turnover rate, $\rho = 0.344$; years in a month, $\theta = 1/12$, and vacancy hazard, $\alpha = 0.675$.

Before 1942, our arguments suggest that the BLS methodology was biased only because of the omission of an aging bias correction; this we call method 1. From 1942 to 1952, the CPI's response bias was unusually large because of quarterly data collection; we call this method 2.

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[25] Vacancy data is also available from the AHS. The AHS has the drawback that it is conducted from August to November, while the HVS is conducted year-round and is thus unlikely to suffer a strong seasonal bias. The AHS is conducted once every two years; the HVS every month. Samples are roughly the same size; the HVS has about 60,000 units, the AHS about 54,000, but because the HVS units are sampled 24 times in the two-year period during which the AHS is sampled once, the effective size of the HVS sample is much greater.

[26] However, this model does not match the data well beyond six months. The reoccupation rate tends to fall over time; indeed, the vacancy rate in the simple model falls too steeply to match the data from two to four months to four to six months, so it should be kept in mind that α has been calibrated to fit the average three-month and six-month vacancy rates. In experiments with the model where n changes, the model has a low vacancy rate when n=12.

From 1953 to 1963, the mail survey continued to result in very few rent collections from units that changed hands, and method 3 must be revised upward by 40.5 percent in addition to correcting for aging bias. From 1964 to 1977, method 4, the telephone survey raised response rates and the response bias implies an upward revision of 28.5 percent. From 1978 to 1985, method 5, when managers and landlords could be contacted and the price inspectors contact with units rose substantially, vacancy bias and recall bias together resulted in a bias factor of 1.181. Beginning in 1985, with method 6, vacancy imputation eliminated response bias, and only a small amount of recall bias remained in addition to aging bias. Aging bias was corrected in 1988, at which point only a portion of the recall bias remained in method 7. And beginning in January 1994, when the recall formula was abandoned, the CPI rental index required no adjustment, and we dub the resulting method 0.

III.3 Testing the model of response bias: Simulation with BLS microdata

In this section, we test the validity of our parameterized model by using the CPI micro data for rents for the period January 1988 to December 1992. In this period, the BLS was still collecting information from renters about the previous month's rent and the current month's rent and using the recall formula; it imputed missing data for vacancies and other nonresponding units; and it adjusted the data for aging bias. The data set includes information on each housing unit sampled by the BLS. For each unit and collection period, the data set has information on the length of occupancy (one to six months and more than six months); the type of structure; the completeness of the interview or a reason for failure to obtain information; the current month rent—either actual or imputed by the BLS; and last month's rent, actual or imputed. The data also provide information on which observations have been imputed and whether the tenant is

[28] The data set does not have the weights the BLS used to blow up the sample observations to the universe. A simulation using BLS methodology at the time reveals a very small difference in the official non-seasonally adjusted rental inflation and the simulated rental inflation using our unweighted data – our simulation estimates rental inflation of 3.461 percent (not seasonally adjusted annual rate, in logs) from June 1988 to December 1992, compared to 3.438 percent in the published data (Appendix 4). The difference is reduced even further if we avoid the problems of seasonality by using the annual averages for 1989 and 1992 (the difference in inflation rates over the period is just 0.003 percentage point: 3.369 percent annually in our simulation to 3.363 percent in published data). Throughout these simulations we will use data that averages the full year 1992 and the full year 1989.

continuing from the last rent observation or a new occupant. It is thus a very good data set for verifying whether the data the BLS actually used conform to our model behavior, since it provides us the data necessary to compute the impact of changes in BLS practices.[28]

Rental inflation estimates based on microdata. Table 7 shows the microdata estimates of alternative BLS methods of data collection. The first column shows what the measured inflation rate would be, using only the six-month changes in the microdata so these data omit any recall bias. We carry over the method numbering from Table 6. Method 0 includes the imputed rents for vacant units in the microdata and represents the current methodology except it does not include aging bias. It thus represents complete data. Method 3 excludes all recent movers (corresponding to the procedures used from 1953 to 1964, while Method 4 excludes 80 percent of recent movers (corresponding to the procedures used from 1965 to 1977, using our estimate of $q_M/q_C = 0.2$). Method 5 includes only the rent data actually collected from respondents, mimicking the method from 1978 to 1984, with vacancy bias. Method 6 is the method used during the period from 1985 to 1993, ex aging bias, complete data with a small recall bias. The second column shows the one-month data. Column three shows the six-month and one-month data combined using the recall formula. Table 8 shows the data from Table 7 in ratio form, enabling us to compare the ratios implied by our model (as shown in Table 6) to the microdata.

Bias correction factors. In Table 6 we presented the correction factors that our parameterized model suggests for different periods as the BLS changed its rental collection and processing methods. We first discuss how these compared to simulated data. (We are unable to duplicate method 2, the period of quarterly collection from 1942 to 1952, because in the period from which the microdata are taken there was only semiannual collection.) Note that the parameterization of our model uses no data from the microdata set.

From 1953 to 1963, our model suggests that inclusion of new tenants and vacancies would raise the measured inflation rate by 40.5 percent. In the microdata, inclusion of new tenants raises the measured inflation rate by 39.5 percent. The result is almost exactly right.

From 1964 to 1977, our revision suggests that the correction factor in this period needed to eliminate response bias was 28.5 percent, somewhat below the simulation ratio of 32.7 percent. From 1978 to 1984, the correction factor from the vacancy response bias model is 8.6 percent, while the simulation data suggests an 11 percent upward correction.

All errors in our ratios to the complete data were less than 25 percent and in most cases much less. All the larger errors imply that our correction factors are too conservative. Note further that the Rivers and Sommers data we used to calibrate the model were from a period of close to double-digit inflation, while in the simulation period inflation was about 3 percent. Thus, it appears likely that our formulas are almost certainly a better approximation to the true inflation rate than the original published data.

IV. Modelling and Parameterizing the Consequences of Recall Bias and Sampling Frequency

The empirical consequence of recall bias for a sample period was discussed briefly in Armknecht et al. (1995), but it was not clear from that paper how to estimate the impact of recall bias for other periods of time. The first discussion of recall bias was in Rivers and Sommers (1983), who noted that while 24,182 six-month changes were reported between April 1979 and March 1981, only 2,541 one-month changes were reported. The number of reported one-month changes is just 63 percent of the 4,030 expected based on the number of six-month changes. They argued that a large percentage of one-month changes are not being recalled or reported. (Interestingly, managers and landlords provide fewer one-month rent changes than do tenants.) There is no similar problem with the six-month change, because the six-month-earlier rent has been recorded in the previous visit, and so does not rely on tenant or manager recall.

Rivers and Sommers did not provide an analytical account of the impact of recall bias and the use of the recall formula. In Appendix 1, we show that given the weights in the recall formula for the six-month and one-month changes in rents, a bias of size e in the recall of the monthly change in rent creates an index bias of 0.2364e. Since Rivers and Sommers found that 37 percent of expected one-month changes were omitted, the expected bias would be 37 percent x 0.2364 = 8.75 percent. Correcting the response bias should raise the measured inflation rate by 9.6 percent.[29] The Armknecht et al. (1995) estimate that recall bias was 9 percent of the inflation rate is close to this analytical bias estimate.

The recall formula. Now let us test our recall formula using the 1988-1992 rent microdata. During this period, the BLS was using imputations to fill in data for a large proportion of observations. It used the six-month relatives for recent movers to impute the six-month relatives for vacancies and other nonresponders and obtain the current rental price. It also imputed estimates of one-month inflation rates by assuming a proportion of the six-month rate was appropriate.

In the actual one-month rental increase data (without vacancy imputations), the average annualized rate of increase (1.676 percent) is only 60.5 percent as much as the average annualized rate of increase in the six-month actual changes (2.767 percent). The vacancy imputations raise the annualized rate of increase in the six-month rental increase data by 11 percent, from 2.767 percent to 3.071 percent, and they raise the annualized rate of increase in the one-month rental increase data by 69 percent, from 1.676 to 2.835 percent.

Using the methods corresponding to the 1978 to 1984 period, the recall formula reduced the measured inflation rate from 2.767 percent to 2.509 percent. To eliminate this recall bias thus raises the rental inflation rate by 10.3 percent, close to our modeled estimate of 9.6 percent.

On the other hand, vacancy imputations not only correct the six-month data, they also correct the one-month data. As a result, the impact of the recall formula on the imputed data is to lower the measured inflation rate by only 2 percent, from 3.071 to 3.010 percent. This implies that e has been reduced to about 0.08 π. This closely matches Rivers and Sommers' expected impact of vacancy imputations on recall bias.

The value of the recall formula in smoothing the six-month relatives is evident in Figure 2. Here we have graphed separately the two parts of the recall formula, using the one-month price changes to create two inflation series that use only the one-month data (using the formula

[29] 1/(1-0.0875)=1.096.

$I_1(t) = Rt,t\text{-}1\ I_1(t\text{-}1)$) and the six-month price changes to create three inflation series (using the formula $I_6(t) = Rt,t\text{-}6\ I_6(t\text{-}6)$.) For the one-month data, we create a series without the vacancy imputations (actual data) and with the imputations (complete data). The strikingly faster rate of inflation with the imputations can be seen clearly. For the six-month data, we create series corresponding to continuing tenants only (the 1953 to 1963 method), all tenants without vacancy imputations (actual data), and all tenants including vacancy imputations (complete data).

As can be seen, in all cases the one-month relatives are distinctly smoother than the six-month relatives. Referring to Figure A1 in Appendix 4, the recall formula gives a far stabler series as well, precisely what the formula was designed to do. It is tempting to use a formula such as $I_6(t) = Rt,t\text{-}6\ I_6(t\text{-}6)$, because this formula does not create an artificial three-month lag in the published series as the current BLS formula does. But as can be seen, it introduces noise into the series in the form of a substantial sawtooth.

One way of eliminating the lag introduced by the BLS formula would be to sample rents more frequently. If rents were collected monthly, the lag would disappear. But this is a costly practice which would require six times as much data collection to generate approximately the same number of price changes. We therefore now turn to the tradeoff between the cost of sampling frequency and data accuracy. This issue is not entirely historical – some countries, such as Germany, collect rent data quarterly rather semiannually.

IV. 1 Analyzing sampling frequency

Because rents usually don't change more than once a year, the frequency of data collection at each unit plays a role in the timing and accuracy of the inflation measure. If the price collection agency samples more frequently, inflation may be detected sooner, but given a budget for a constant number of price observations, the more frequent sampling of fewer units results in less precision.

How often to obtain observations. If we price each unit in our sample every month, only one-twelfth of our price observations will show a price increase, but we will know that the price increases we do observe occurred in the past month. On the other hand, if we price each unit every 12 months, all of our price observations will show an increase, but the price increase for any individual unit may have occurred at any time in the past year, and the recorded rate of inflation will be the average of increases over the past year.

We could ask respondents to tell us exactly when the price increase occurred and thereby obtain a more accurate picture, except that respondents are generally not very good at doing this, and as we have noted, efforts in this direction have been abandoned. The BLS's current practice for rents is to sample every six months and to record the monthly rental price increase as the sixth root of the average price increase observed.

We next show explicitly the tradeoff between timeliness and precision of observation, given a fixed number of price observations; we show that the variance of our estimates of inflation is inversely proportional to the number of months between observations (when observations are more frequent than rent changes).

Measurement error associated with sampling frequency. Under an annual lease, the log rental price p_{it} for unit i at month t follows a transition path such that $p_{it} = p_{it-1}$ with probability 1 - θ and $p_{it} = x_{it} + p_{it-1}$ with probability θ, where $x_{it} = \pi_t + e_{it} > 0$, θ = 1/12, and e_{it} has zero mean and standard deviation σ. Here π_t is the underlying annual rate of rental inflation, so that $Ep_{it} = \theta\pi_t + p_{it-1}$.

We sample the log rent p_{it} and wish to form estimates of $\theta\pi_t = Ep_{it} - p_{it-1}$. If we sample m rental units every month, and there are no missing observations, we obtain $x_{it} = p_{it} - p_{it-1}$ or 0 according to a binomial distribution with parameters m and θ. The estimates can thus be modeled as a random sum $\theta\hat{\pi}_t = \sum_{i=1}^{m} \frac{p_{it} - p_{it-1}}{m} = \frac{1}{m}\sum_{i=1}^{s} \pi_t + e_{it}$ where s, the number of rental units whose rent changed, is distributed binomial with parameters m and θ.[30] The expectation of the random sum is the expected value of s times the expected value of terms being summed, in this case mθ times $\frac{\pi_t}{m}$. The variance of the random sum is the variance of s (=mθ(1-θ)) times $\frac{\pi_t^2}{m^2}$

[30] The mean and variance of a random sum of random variables have a well-known derivation; see Appendix 2.

plus the expected value of s (=mθ) times the variance of the term being summed, or $\frac{\sigma^2}{m}$. Thus the average monthly inflation measure has mean $\theta\pi_t$ and variance $\frac{\pi_t^2\theta(1-\theta)}{m}+\frac{\theta\sigma^2}{m}$, so variance is inversely proportional to m.

Alternatively, one can sample each unit every n months and obtain p_{it} and p_{it-n}, sampling m units a month. From each unit, we obtain a price increase x_{it-j} ($j \varepsilon [0 .. n-1]$) with probability nθ (assuming $n < 1/\theta$), and thus the number of price increases recorded follows a binomial distribution with parameters m and nθ. Our observations $\Sigma p_{it}-p_{it-n}/m$ have mean $\sum_{j=0}^{n-1}\frac{\theta\pi_{t-j}}{n}$ and variance $\left(\sum_{j=0}^{n-1}\frac{\pi_{t-j}^2}{n}\right)\frac{\theta(1-\theta)}{mn}+\frac{\theta\sigma^2}{mn}$, so variance is inversely proportional to mn. By sampling each unit less frequently and sampling more units, we reduce the variance of the error term, at the cost of observing values of $\sum_{j=0}^{n-1}\frac{\pi_{t-j}}{n}$ rather than π_t, so our inflation measure is, on average, out of date by n/2 periods. This is the procedure that the BLS has followed since 1994 with n = 6; the monthly rate of change is the sixth root of the observations taken at six-month intervals.

V. A New Measure of Rental Inflation, 1940-2001

In 1999 Stewart and Reed published an adjusted CPI that incorporated the adjustments for recall bias and aging bias into the historical rental inflation series. We believe that to correctly adjust the historical data, a further adjustment needs to be made for nonresponse bias. In creating our new estimates of the rental inflation, we developed estimates of the impacts of the impact of increased response rates for new renters, recall bias, and of vacancy imputation and have used estimates of aging bias from the BLS. Our new rental price series imply that historical measures of U.S. aggregate inflation, including the personal consumption expenditure (PCE) deflator, the CPI, and the CPI-U-X1, included a downward bias in rents of 1.6 percentage points a year over the entire period from 1940 to 1985.

Annual rental price indexes for December of each year from 1940 to 2000 for our revised estimates of the rent series are presented in Appendix Table 1.

V.1 Comparing alternative rental inflation estimates

In this section we attempt to assess the reasonableness of our revised CPI for rents by comparisons with a number of other data series. In Section I we observed that the CPI for rents from roughly 1940 to 1985 had a different growth rate compared to the data for median rents (Table 1). Does our new series appear to be more closely aligned with median rents and other data series on inflation and real growth?

Table 9 shows the relationship between median gross rent and rental inflation data. As the final column shows, the revision reduces the gap between the CPI rental inflation and the median rent growth rate, but in the period 1940 to 1985 does not eliminate it. From 1985 to1995, however, our revised rental inflation was only roughly 0.2 percentage point less than median rent, annually, which implies a small quality increase over the period. In the most recent period, 1995 to 2001, we do not revise the CPI rent measure, as we believe that tenant rents were correctly calculated. In this period, the rental inflation measure grew 0.3 percentage point faster than median rent, implying that the quality of the rental stock was falling modestly.

Table 10 gives old and new estimates of rental inflation from 1975 QIV to 2001 QIV together with econometric estimates of rental inflation based on microdata from the American Housing Survey. These econometric estimates are from Crone et al. (2004); we use fourth quarter data to match the timing of the American Housing Survey. The rental inflation measures are based on Box-Cox hedonic regressions and on repeat rent models The Box-Cox rental inflation rates are relatively close to those of the adjusted CPI for rent, particularly in the period from 1975 to 1985 when the CPI adjustments are the largest. These provide some supportive evidence for the reasonableness of the adjustment.

On the other hand, the repeat rent estimates that use the panel subsamples of the AHS are closer to the unadjusted CPI rent measures. One difference is that the repeat rent measures do not include an adjustment for aging bias. However, that accounts for only 0.4 percentage point of the 2.0-percentage-point gap between the two series during the crucial period from 1975 to

1983. A more important issue is that the repeat rent estimates may suffer from response bias, as a high proportion of observations are missing in the panel data.

Table 11 shows long-term inflation rates for the periods 1940 to 1985 and 1985 to 2001. In Tables 11 and 12 we use annual data, which we are able to obtain back to 1940. The PCE tenant rent and owner-occupied rental equivalent housing services price indexes closely mirror the long-run inflation rate of the CPI for tenant rents of the BLS, as the BEA depends primarily on the CPI for tenant rents in constructing these deflators. In the period before 1985, these official rent estimates tend to be well below not only our revised rent estimate and the median gross rent but also the BEA's residential fixed investment chain price deflator. The official rent inflation estimates are also well below all the other U.S. aggregate price inflation measures. We use the CPI-W excluding shelter because that provides a well-known measure of CPI that excludes rents (it also excludes the problems associated with the use of the mortgage interest rate in the CPI before 1983). We also include the personal consumption deflator, the GDP deflator, and the PPI all-items price index (linked to the old wholesale price index). These data all suggest that the published rental inflation rates are anomalously low.

In sharp contrast, in the period from 1985 to 2001, where we have argued that the official rent inflation measures are generally correct, all the rental inflation measures are generally rising faster than the aggregate price measures, consistent with slower productivity growth in construction than in other parts of the economy.

Comparing the two periods, the unrevised CPI and PCE rental inflation measures show almost no deceleration between the two periods, slowing by less than 0.2 percentage point. This lack of deceleration stands in contrast to alternative measures of inflation that show deceleration of between 1.6 and 3.6 percent. The revised CPI rental measure shows a deceleration much closer to the other price measures. This also suggests that the unrevised measures are anomalous.

Table 11 shows broad growth rates. Figure 2 presents centered three-year moving average, annualized inflation rates to show that for most of the period from 1940 to 1985 the official CPI rental inflation rate was below the CPI and GDP inflation measures, while for most of the period after 1985 the reverse was true. Ordinarily, these movements in relative prices would be data to be explained. However, given the strong grounds we have developed for suspecting that the old CPI-W for rent understated inflation from 1940 to 1985, these data reinforce our skepticism.

Table 12 compares the growth rates of the two PCE measures of housing services with alternative measures of real activity. The revised measure of real PCE housing services is constructed by deflating owner-occupied, tenant, and farm dwellings with the revised CPI-W. Other – primarily hotels – is small and left unchanged. The BEA net stock quantity index for residential fixed assets is constructed by the perpetual inventory method and reflects the real stock of housing net of depreciation. One would expect a relatively stable relationship between the BEA's measure of the residential net stock and PCE for real housing services, since the housing services are those provided by the stock of housing. From 1985 to 2001, the BEA's measure of housing services grows at the same rate as the net stock, as one would expect. However, from 1940 to 1985, BEA's measure grows much faster, consistent with the possibility that inflation has been understated and housing services growth overstated.

In Figure 3, we show the ratio of the BEA's measure of real housing services to its measure of the net residential stock. As we can see, the measure is quite stable after 1985. On the other hand, there is a steady rise in the ratio from 1940 to 1985. In 1940, the net stock of housing provides less than half the services per unit than in 1985. By contrast, the relationship between our revised measure of housing services and the net stock is relatively stable. The revised measure of housing services and the net stock measure – though derived from entirely different procedures and data – tell a broadly consistent story, while the unrevised measure does not.

Table 12 further shows that the BEA's measure of housing services grew faster from 1940 to 1985 than the rate of residential fixed investment, real gross domestic product, and real personal consumption expenditures. By contrast, from 1985 to 2001 it grew either about as fast as or slower than other measures of real activity. The last two rows show that both payroll and population growth decelerated over the two periods, in line with the deceleration of other measures of economic activity. We argue that these data are also supportive of the revised estimates of housing services growth, and thus of the revised CPI rental inflation measures.

VI. Summary

We have argued in this paper that the rate of rental inflation was quite substantially underestimated in the period from 1942 to 1985, by about 1.4 percentage points annually. The BLS long suspected a problem with the data and fixed the bias, step by step, over the course of decades. In this paper, we have modelled the impact of nonresponse bias – the main source of the rental inflation bias – and calibrated our model with data from the American Housing Survey, the Housing Vacancy Survey, and a BLS microdata study from the period 1979 to 1981. We then verified our estimates using BLS microdata from the period 1988 to 1992. Finally, we have shown that our estimates of substantial bias are consistent with other economic statistics, using a variety of alternative measures of inflation and growth.

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List of symbols used

p_{it} log rental price
i unit
t month
θ probability price increase
x_{it} log price increase
π expected log price increase, annual rate of inflation
e_{it} noise term
σ standard deviation of e
m no. of units sampled
s no. of units whose rent changed
n no. of months between rent samples
ρ probability tenant leaves
$1-\alpha$ probability of new tenant occupying vacant unit
$a \equiv \alpha(1-\alpha^n)/n(1-\alpha)$
π_{Ct} inflation rate for continuing tenant
$(1+b)\pi_{Ct}$ inflation rate when tenant moves
q_M probability of recording inflation rate when tenant moves
q_C probability of recording inflation rate when tenant continues
π^m mean measured rental inflation

I(t) Rent Index
Rt,t-k change in rent from k months ago
μ monthly rate of inflation
d coefficient of recall bias
e recall bias

Appendix 1
Calculation of recall bias on measured rental inflation

What is the quantitative impact of a given recall bias on measured rental inflation? Suppose the *monthly* inflation rate in the six-month relatives is μ. The six-month relative will be $(1+\mu)^6$. If the one-month recall bias is e, then the reported one-month change will be μ - e. The formula given in equation (1) to compute the rental index can then be written as the following sixth order difference equation:

$$I(t) = 0.65(1+\mu-e)\, I(t-1) + 0.35\, (1+\mu)^6\, I(t-6). \qquad \text{(A1)}$$

To linearly approximate the bias, we assume that measured monthly relative in the steady state equals

$$1 + \mu - de$$

where

d = the first order impact on the measured inflation rate of the recall bias e.

Then

$$I(t) = (1+\mu-de)\, I(t-1) \quad \text{and}$$

$$I(t) = (1+\mu-de)^t\, I(0).$$

To compute d we substitute and obtain:

$$(1+\mu-de)^t\, I(0) = 0.65(1+\mu-e)(1+\mu-de)^{t-1}\, I(0) + 0.35\, (1+\mu)^6\, (1+\mu-de)^{t-6}\, I(0)$$

Dividing through by $(1+\mu-de)^{t-6}$ I(0) and subtracting the right-hand side, we obtain:

$$1 - 0.65(1+\mu-e)/(1+\mu-de) - 0.35\, [(1+\mu)/(1+\mu-de)]^6 = 0 \qquad \text{(A2)}$$

Now, performing the division indicated by the second term on the left-hand side of equation (A2):

$$(1+\mu-e)/(1+\mu-de) = 1- e\, (1-d) + \text{error}\, . \qquad \text{(A3)}$$

The error term is actually $(\mu-de)((e\,(1-d))/(1+\mu-de)$. Both μ and e are assumed to be much smaller than one (μ is the *monthly* inflation rate and e is its bias) and d is less than one. Therefore, the error is on the order of μ times e. Performing the division indicated by the third term on the left-hand side of equation (A2):

$$(1+\mu)/(1+\mu-de) = 1 + de + \text{error} \quad \text{(A4)}$$

The error is actually $(\mu\text{-}de)de/(1 + \mu - de)$, and for the reasons mentioned above, the error is on the order of μ times e. Ignoring the error and raising the right-hand side of equation (A4) to the sixth power, we obtain

$$(1+de)^6 = 1 + 6de + \text{error} \quad \text{(A5)}$$

where the error represents all the exponentiated values of de and is therefore very small.

Ignoring the error terms and substituting the right-hand sides of (A3) and (A5) into (A2), we have approximately

$$1 - 0.65\,(1 - e(1-d)) - 0.35\,(1+ 6\,de) = 0$$

$$0.65\,e(1-d) - 0.35(6\,de)=0$$

or

$$d = 0.2364.\text{[31]} \quad \text{(A6)}$$

[31]A simulation over a six-year period with a = .005 and e = .001, so that the annual inflation rate is about 6 percent, yields d = .2362.

Appendix 2
Calculation of rental inflation adjustments for response bias

Assumptions about parameters in model			
Event	Probability of event	Log change in rental	Probability of measurement
Lease in force	$1-n\theta$	0	q_C
Lease ends, tenant stays	$n\theta(1-\rho)$	π_{Ct}	q_C
Lease ends, tenant leaves	$n\theta\rho$	$(1+b)\pi_{Ct}$	q_M

Quantity of successfully recorded responses per measurement attempt: $q_C(1-n\theta\rho)+q_M(n\theta\rho)$

Measured inflation per measurement attempt: $q_C(n\theta(1-\rho)\pi_{Ct}) + q_M(n\theta\rho(1+b)\pi_{Ct})$

Define the annualized inflation rate as π^m_t

Measured inflation for time period $n\theta$:

$$n\theta\pi_t^m = \frac{q_C n\theta(1-\rho)\pi_{Ct} + q_M n\theta\rho(1+b)\pi_{Ct}}{q_C(1-n\theta\rho)+q_M(n\theta\rho)}$$

which simplifies to:

$$\pi_t^m = \frac{1-\rho\left(1-(\frac{q_M}{q_C}(1+b))\right)}{1-n\theta\rho(1-\frac{q_M}{q_C})}\pi_{Ct}$$

Appendix 3
Measurement error associated with sampling frequency

Properties of a random sum of random variables:

Define Z = $\sum_{i=1}^{s} X_i$.

Where X_i are independent with mean X and variance σ_x^2,
and s has mean S and variance σ_s^2
Then, defining E(.) as the expectation and Var(.) as the variance:
E(Z) = SX
Var(Z) is $X^2\sigma_s^2 + S\sigma_x^2$
These are well-known exact results. For a proof see Rice (1995) 138-139.

A corollary is:

Define Z = $\sum_{j=1}^{n}\sum_{i=1}^{s_j} X_{ij}$.

Where X_{ij} are independent with mean X_j and variance σ_x^2,
and s_j are independent with mean S and variance σ_s^2
Then:

E(Z) = $S\sum_{j=1}^{n} X_j$

Var(Z) is $\sigma_s^2 \sum_{j=1}^{n} X_j^2 + nS\sigma_x^2$

Proof: The first follows because Z is the sum of n random sums of random variables, each with mean SX. The second follows because the variance of the sum of independent random variables is the sum of the variances.

In the case where each unit is sampled every month and m units are sampled each month, the measured monthly rate of inflation is:

$$\theta\hat{\pi}_t = \sum_{i=1}^{m} \frac{p_{it} - p_{it-1}}{m} = \frac{1}{m}\sum_{i=1}^{s} \pi_t + e_{it}$$

Where s is binominal with parameters m and θ, with mean mθ and variance mθ(1-θ).
The terms within the summation have mean π_t and variance σ^2.

Thus the expected value of $\theta\widehat{\pi} = \frac{1}{m}(m\theta)\pi_t = \theta\pi_t$

The variance of $\theta\widehat{\pi}$ is

$$\frac{1}{m^2}\left[\pi_t^2 m\theta(1-\theta) + m\theta\sigma^2\right] = \frac{\pi_t^2\theta(1-\theta)}{m} + \frac{\theta\sigma^2}{m},$$

In the case where units are sampled every n months and m units are sampled each month, the measured monthly rate of inflation is:

$$\theta\sum_{j=0}^{n-1}\frac{\hat{\pi}_{t-j}}{n}=\frac{1}{n}\sum_{i=1}^{m}\frac{p_{it}-p_{it-n}}{m}=\frac{1}{mn}\sum_{j=0}^{n-1}\sum_{i=1}^{s_j}\pi_{t-j}+e_{it-j}$$

Since s_j is binominal with parameters m and θ, it has mean mθ and variance mθ(1-θ).
The term $\pi_{t-j} + e_{it-j}$ has mean π_{t-j} and variance σ^2.

Thus the expected value of $\theta\sum_{j=0}^{n-1}\frac{\hat{\pi}_{t-j}}{n}=\frac{1}{mn}(m\theta)\sum_{j=0}^{n-1}\pi_{t-j}=\theta\sum_{j=0}^{n-1}\frac{\pi_{t-j}}{n}$.

The variance of $\theta\hat{\pi}$ is

$$\frac{1}{n^2m^2}\left[\left(\sum_{j=0}^{n-1}\pi_{t-j}^2\right)m\theta(1-\theta)+nm\theta\sigma^2\right]=\frac{\left(\sum_{j=0}^{n-1}\frac{\pi_{t-j}^2}{n}\right)\theta(1-\theta)}{nm}+\frac{\theta\sigma^2}{nm}$$

Appendix 4

Simulation: Are the missing weights a large problem?

In this simulation we use all the rental data, imputed and actual, to see whether our data match published BLS data despite the fact that our data lack the unit-by-unit weights that the BLS uses to construct its aggregates.

The BLS procedure under the recall formula involved calculating and aggregating two inflation rates. The first is called the six-month relative, the ratio of the weighted sum of the rents for the current period to the weighted sum for the period six months ago, using all units for which data are available. The second is called the one-month relative, a similar ratio of the current rents to the previous month rents. These two relatives are then combined using the recall formula. We can duplicate this except that we do not have the weights for the individual units, so we take a simple average. We then add 0.36 percent annually (0.03 monthly) to the inflation rate to compensate for the aging bias. We begin in July 1988 (we can only construct six-month relatives beginning in July 1988) and continue until December 1992. For the period from June 1988 to December 1992, our annualized inflation rate (in logs) is 3.461 percent, while the published measure for the same period is 3.438 percent, a difference of less than 1 percent. The two data series behave somewhat differently, with our data showing a mild tendency for seasonal variation relative to the published not seasonally adjusted BLS data, as can be seen on Figure A1.

The tendency for a few data points at seasonal frequencies to move relative to the total is of concern because the endpoint may affect conclusions. In particular, for our data, the CPI simulation series for March varies from the published level in successive years from 1989 to 1992 by 0.05 percent, 0.12 percent, 0.28 percent, and 0.39 percent. This is not surprising in that according to Armknecht et al. (1995) the recall formula tended to cause sawtooth patterns in the data. Nevertheless, this seasonal difference raises the possibility that the close agreement between the two series at December 1992 is happenstance. We can remove the seasonal influence if we average both data series for the last year. When we do so, we find that the average of the full year 1992 over the full year 1989 agrees even more closely for the two series, 3.369 (our simulation) to 3.363 percent (published CPI.) This difference is about 0.2 percent.

Appendix Table 1. Indexes of tenant rent, U.S. CPI-W and new series, 1940-2000, 1982-84 = 100		
December, not seasonally adjusted	BLS CPI-W, Rent of primary residence	New series
1940	23.8	12.9
1941	24.7	13.5
1942	24.7	13.5
1943	24.8	13.7
1944	24.9	13.8
1945	24.9	13.8
1946	25.2	14.2
1947	26.9	15.7
1948	28.2	17.0
1949	29.3	18.1
1950	30.2	19.0
1951	31.7	20.6
1952	33.1	21.9
1953	35.0	23.8
1954	35.4	24.3
1955	35.9	24.9
1956	36.8	25.8
1957	37.4	26.5
1958	38.0	27.2
1959	38.6	27.9
1960	39.1	28.5
1961	39.6	29.2
1962	40.0	29.7
1963	40.4	30.2
1964	40.8	30.7
1965	41.2	31.2
1966	41.9	32.0
1967	42.8	33.0
1968	44.0	34.3
1969	45.6	36.1
1970	47.7	38.3
1971	49.5	40.4
1972	51.2	42.3
1973	53.7	45.1
1974	56.6	48.5
1975	59.5	51.9
1976	62.8	55.8

Appendix Table 1, continued		
December	BLS CPI-W	New series
1977	66.9	60.7
1978	71.7	66.2
1979	77.4	72.8
1980	84.4	80.9
1981	91.5	89.4
1982	97.5	96.8
1983	102.2	102.7
1984	108.1	110.2
1985	115	117.8
1986	120.8	124.3
1987	125.3	129.5
1988	129.7	134.1
1989	135	139.7
1990	140.2	145.2
1991	144.8	150.0
1992	148.2	153.6
1993	151.6	157.2
1994	155.4	161.2
1995	159.3	165.2
1996	163.7	169.8
1997	168.8	175.1
1998	174.6	181.1
1999	179.9	186.6
2000	187.0	193.9

Table 1. Median gross rents compared with rental price as measured in the US BLS CPI-W, annualized log growth rates in percent			
	Median gross rent	Tenant rental prices, CPI-W (based on annual averages)	Change in median gross rent minus CPI for rent
1930-40	-2.4 *	-2.7	0.4
1940-50	4.5	2.3	2.3
1950-60	5.1	2.6	2.5
1960-70	4.2	1.8	2.4
1970-77	7.6	4.8	2.9
1977-85:	8.5	6.8	1.8
1985-95	3.6	3.4	0.2
1995-2001	3.2	3.3	-0.1
1940-85	5.8	3.4	2.4

*Median contract rents

Sources: Median rents: Decennial Censuses of Housing (1930 to 1970), American Housing Survey (1977 to 2001)

All CPI data: Haver Analytics. Data for a given year are the average of monthly CPI seasonally unadjusted.

Table 2. Turnovers and vacancies				
	(1) Vacancy Survey	(2) AHS & Census	(3) Housing Completions	(4) Turnover
Year	Occupied rental units	recent movers	Multifamily	=[(2)-(3)]/(1)
1970	22806	7707*	618.0	31.1%
1971	23266		688.1	
1972	23849		839.9	
1973	24425	8892	902.3	32.7%
1974	24943	9426	792.7	34.6%
1975	25462	9698	445.9	36.3%
1976	25897	9924	341.7	37.0%
1977	26324	10302	397.0	37.6%
1978	26810	9940	496.3	35.2%
1979	27174	9885	570.6	34.3%
1980	27416	10116	547.0	34.9%
1981	28709	10862	446.5	36.3%
1982	29495		373.6	
1983	29894	9958	464.9	31.8%
1984	30675		623.6	
1985	31736	12166	632.0	36.3%
1986	32302		638.3	
1987	32602	12275	548.3	36.0%
1988	33292		446.0	
1989	33734	12303	397.5	35.3%
1990	33976		343.3	
1991	34242	12230	254.8	35.0%
1992	34568		193.4	
1993	35184	11524	153.2	32.3%
1994	35557		185.0	
1995	35246	12251	246.5	34.1%
1996	34943		283.0	
1997	35059	11969	284.6	33.3%
1998	34896		315.4	
1999	34830	11349	333.3	31.6%
2000	34470		332.7	
2001	34417	11641	314.7	32.9%
2002	34826		321.4	
average				34.4%

Sources: (1) Housing Vacancy Survey, (2)*Census of Housing (1970), 7644 divided by 1.216 to account for 5 quarter period (see text), American Housing Survey (1973-2001), (3) Residential Construction Survey (4) Housing Vacancy Survey.

Table 3. Six-month rent increases from Rivers and Sommers, 1983 Data collected October 1979 to March 1981, reflecting six-month changes from the period April 1979 to March 1981, log percent changes						
(1) Occupancy status	(2) Number surveyed	(3) Number with six-month rent change	(4) Proportion with rent change	(5) Average rent change for units with change	(6) Average rent change for all units	(7) Average rent change for all units, annualized
6 months or more	37144	17243	46.4 %	8.56	4.07	8.1
5 months or less	8614	6939	80.6 %	11.40	9.28	18.6
all occupants	45758	24182	52.8 %	9.38	5.07	10.1
vacancies	3833					
other nonresponses*	3868					

Data from Rivers and Sommers, 1983, pp. 202-203, tables "Analysis of Six-Month Rent Changes by Length of Occupancy" and "Interview Classification."
* Includes no one at home (2619), refusal (745), and other (504).

Table 4. Comparison of CPI rent measures for overlap period, January 1978 to June 1978

	CPI-W (OLD)	CPI-W (NEW)	CPI-U (NEW)
Dec 1977	157.9		
January 1978	158.7	158.8	158.8
February 1978	159.7	159.7	159.7
March 1978	160.6	160.5	160.5
April 1978	161.4	161.4	161.5
May 1978	162.2	162.6	162.7
June 1978	163.0	163.5	163.6

Note: When a major change is instituted in CPI methodology, the BLS sometimes collects data for six months under the old methodology as well as under the revised methodology. In the case of the 1978 revision, in addition to the numerous procedural innovations, BLS introduced a CPI for all urban consumers (the CPI-U) in addition to the revised CPI for urban wage earners and clerical workers (CPI-W). During the overlap period, from January to June 1978, the BLS published statistics for the old CPI as well as the two new ones. This had the primary benefit of giving contracts that are indexed to the old data more time for changeover. But it also permitted analysis of the direct impacts of the change. The numerical impact of the 1978 revision on the aggregate CPI as revealed in the overlap data was discussed in Layng (1978), but rental inflation was not commented on specifically. Table 2 presents the 1978 overlap statistics for tenant rents. During the overlap period, the CPI for rents rose roughly 10 percent faster under the revised methods than under the old. The old CPI-W for rents did not accelerate, but the new CPI-W for rents did, and the new CPI-U for rents rose even a bit more.

Table 5. Housing Vacancy Survey. Data are a simple average of available data. Dates published are 1960, 1970, 1975 and 1980 to 2001.

Model uses formula for cumulative vacancy rate: $\frac{\rho\alpha\theta(1-\alpha^n)}{1-\alpha}$ where n is the number of months vacant, with ρ=.344 and α=.675.

	1960, 70, 75	1980-2001	Model estimates
Total vacancy	6.47	7.23	5.95
1 month or less	2.14	2.20	1.94
1 to 2 months	0.95	1.27	1.31
2 to 4 months	1.08	1.36	1.48
4 to 6 months	0.58	0.74	0.67
less than 6 months	4.75	5.58	5.39
6 months or more	1.73	1.66	0.56

Table 6. Corrections for changes in BLS procedures for collecting rents				
Model estimates of the multiplicative factor needed to adjust CPI to true inflation rate given various parameter estimates. Turnovers partially omitted formula: $\dfrac{(1+\rho b)(1-n\theta\rho(1-\frac{q_M}{q_C}))}{1-\rho(1-\frac{q_M}{q_C}(1+b))}$ (1942-1977) Vacancies omitted formula: $\dfrac{1-\theta vn}{1-v\dfrac{1+b}{1+\rho b}}$ where $v=\dfrac{\rho\alpha\left(1-\alpha^n\right)}{n(1-\alpha)}$ (1978 to 1984)				
Method	Periods	Problems	Parameters	Formulas to create revised inflation rate
			All rows: θ=1/12, b= .33 ρ=.344	
1	Before January 1942	Aging bias		π_{BLS1} + .36
2	January 1942 to December 1952	Response bias, quarterly collection, aging bias	q_M/q_C = 0, n= 3,	1.551 π_{BLS2} +.36 %
3	January 1953 to December 1963	Response bias, semiannual collection, aging bias	q_M/q_C =0, n=6	1.405 π_{BLS3} + .36 %
4	January 1964 to December 1977	Response bias, semiannual collection, aging bias	q_M/q_C = 0.2, n=6	1.285 π_{BLS4} + .36 %
5	January 1978 to December 1984	Vacancy bias, recall bias, aging bias	n = 6, α=0.675	1.190 π_{BLS5} + .36 %
	of which:	Vacancy bias	n = 6, α = 0.675	1.0859
		Recall bias	d = 0.2364 e = 0.37 π	1.0959
6	January 1985 to December 1987	Recall bias (1/5 remaining), aging bias	d = 0.2364 e = 0.074 π	1.018 π_{BLS6} + .36 %
7	January 1988 to December 1993	Recall bias (1/5 remaining)		1.018 π_{BLS7}
0	January1994 to present			π_{BLS0}

Table 7. Simulation of alternative rent methodologies: Annualized (log) inflation rates 1989 to 1992, year average (percent) No adjustments for aging bias applied			
Methodology vintage	6 month rates	1 month rates	Recall Formula
1953 to 1964: $q_M = 0$	2.201 (method 3)		
1965 to 1977: $q_M/q_C=0.2$	2.314 (method 4)		
1978 to 1984: Actual Data	2.767** (method 5NR)	1.676	2.509 (method 5)
1985 to 1993: Complete Data (with vacancy imputations)	3.071 (method 0NA)*	2.835	3.010 (method 6)

Source: BLS microdata; see text.

*Method 0NA is method 0 (current practice) except not adjusted for aging bias. This corresponds to complete data.

**Method 5NR is method 5 (the method from 1978 to 1984) without recall bias.

Table 8. Comparison of simulated BLS microdata, 1988 to 1992, to parameterized model estimates			
Correction factor (not including aging adjustment)	Ratios of rental inflation rates for simulation	Simulation based on 1989-92 micro data	Parameterized model estimates
1953 to 1963	methods 0NA and 3	1.395	1.405
1964 to 1977	methods 0NA and 4	1.327	1.285
1978 to 1984	methods 0NA and 5	1.224	1.190
1985 to 1993	methods 0NA and 6	1.021	1.018
1964 method change (20 percent more response)	methods 3 and 4	1.051	1.094
1978 method change (more complete response, response bias)	methods 4 and 5	1.084	1.088
1985 method change (vacancy imputation)	methods 5 and 6	1.195	1.160
Recall bias	method 5 and 5NR	1.103	1.096
Impact of vacancy imputation on vacancy response bias	methods 0NA and 5NR	1.110	1.086

Table 9. Official estimates of CPI for rent, Revised CPI for rent, and Gap between Median Rents and CPI, December to December, 1930 to 2001						
	1	2	3	4	5	6
	Original CPI-W for rent	Revised CPI	Change in median gross rent	Rental inflation gap, median vs. CPI	Revision	Revision as proportion of gap
1930-40	-2.7	-2.7	-2.4 *	0.4	0.4	1.00
1940-50	2.4	3.9	4.5	2.1	1.5	.68
1950-60	2.6	4.1	5.1	2.6	1.5	.58
1960-70	2.0	3.0	4.2	2.2	1.0	.44
1970-77	4.8	6.6	7.6	2.8	1.8	.62
1977-85:	6.8	8.2	8.5	1.8	1.4	.84
1985-95	3.3	3.4	3.6	0.4	0.1	.33
1995-2001	3.4	3.4	3.2	-0.3	0	.00
1940-1985	3.5	4.9	5.8	2.3	1.4	.61

Sources: Decennial Censuses of Housing, American Housing Survey, and CPI.

Table 10
Comparison of CPI-U rental inflation rates with alternative rental inflation measures based on American Housing Survey microdata, log percent annualized rates

	Median gross rents, AHS	CPI-U, rent, IVQ to IVQ	Revised CPI-U, rent, IVQ to IVQ	Box-Cox Hedonic measure, AHS	Repeat rent Measure, AHS
1975-77	8.3	5.7	7.8	8.9	6.9
1977-79:	8.2	7.4	9.1	8.5	6.7
1979-81	10.9	8.3	10.2	10.7	8.6
1981-83	7.7	5.7	7.2	6.9	5.9
1983-85	7.2	5.9	6.8	7.0	not available
1985-87	4.6	4.4	4.7	5.4	4.2
1987-89	3.0	3.9	3.9	5.3	4.9
1989-91	4.3	3.5	3.6	5.7	5.0
1991-93	2.6	2.3	2.3	2.8	3.3
1993-95	3.6	2.5	2.5	3.9	3.6
1995-97	2.4	2.9	2.9	1.5	2.6
1997-99	2.7	3.1	3.1	4.7	3.6
1999-2001	4.4	4.2	4.2	3.2	4.2
Average Rate 1975-83	8.8	6.8	8.6	8.7	7.0
Average Rate 1985-2001	3.4	3.3	3.4	4.1	3.7
Average Rate 1975-2001	5.4	4.6	5.3	5.7	not available

Sources: American Housing Survey, CPI, and authors' calculations. CPI-U is CPI-W before 1978, when the CPI-U was introduced.

Table 11. Comparison of alternative rent price indexes with other price indexes, log percent annualized inflation rates underlying data are annual average price levels				
		1940 to 1985	1985 to 2001	Difference
Official rent estimates	CPI-W, not seasonally adjusted, tenant rents, BLS	3.43	3.37	-0.06
	PCE chained price index, housing services: tenants, BEA	3.62	3.45	-0.17
	PCE, chained price index housing services: owners equivalent, BEA	3.59	3.52	-0.07
New rent estimate	Adjusted CPI-W rents, new estimates	4.84	3.46	-1.38
Median rents	Median gross rents, Census and American Housing Survey, Census Bureau	5.78	3.45	-2.33
Residential structures	Residential fixed investment chain price index, BEA	5.06	3.15	-1.91
Aggregate price measures	CPI-W all items excluding shelter, BLS	4.50	2.81	-1.69
	PCE chained price index, BEA	4.39	2.64	-1.75
	GDP chained price index, BEA	4.37	2.40	-1.97
	PPI all items, BLS	4.51	1.64	-2.87
Wage measure	Average Hourly Earnings, manufacturing, BLS	6.40	2.82	-3.58

Sources: U.S. Bureau of Economic Analysis, U.S. Bureau of Labor Statistics

Table 12. Comparison of real housing services estimates with alternative real growth measures, year average data

		1940 to 1985	1985 to 2001	Difference
Housing services	Real PCE housing services, BEA	4.63	2.44	-2.19
	Real PCE housing services adjusted, new estimates	3.52	2.49	-1.04
Residential net stocks	Real net stock of residential fixed assets, BEA	2.93	2.54	-0.39
Residential investment	Real residential fixed investment, BEA	3.78	2.56	-1.22
Aggregate activity	Real GDP, BEA	3.93	3.05	-0.87
	Real PCE, BEA	3.71	3.31	-0.39
Demographic	Nonfarm Payrolls, BLS	2.45	1.88	-0.56
	Population, Census Bureau	1.31	1.13	-0.18

Sources: U.S. Bureau of Economic Analysis, U.S. Bureau of Census

Figure A1. Published and Simulated CPI Rents

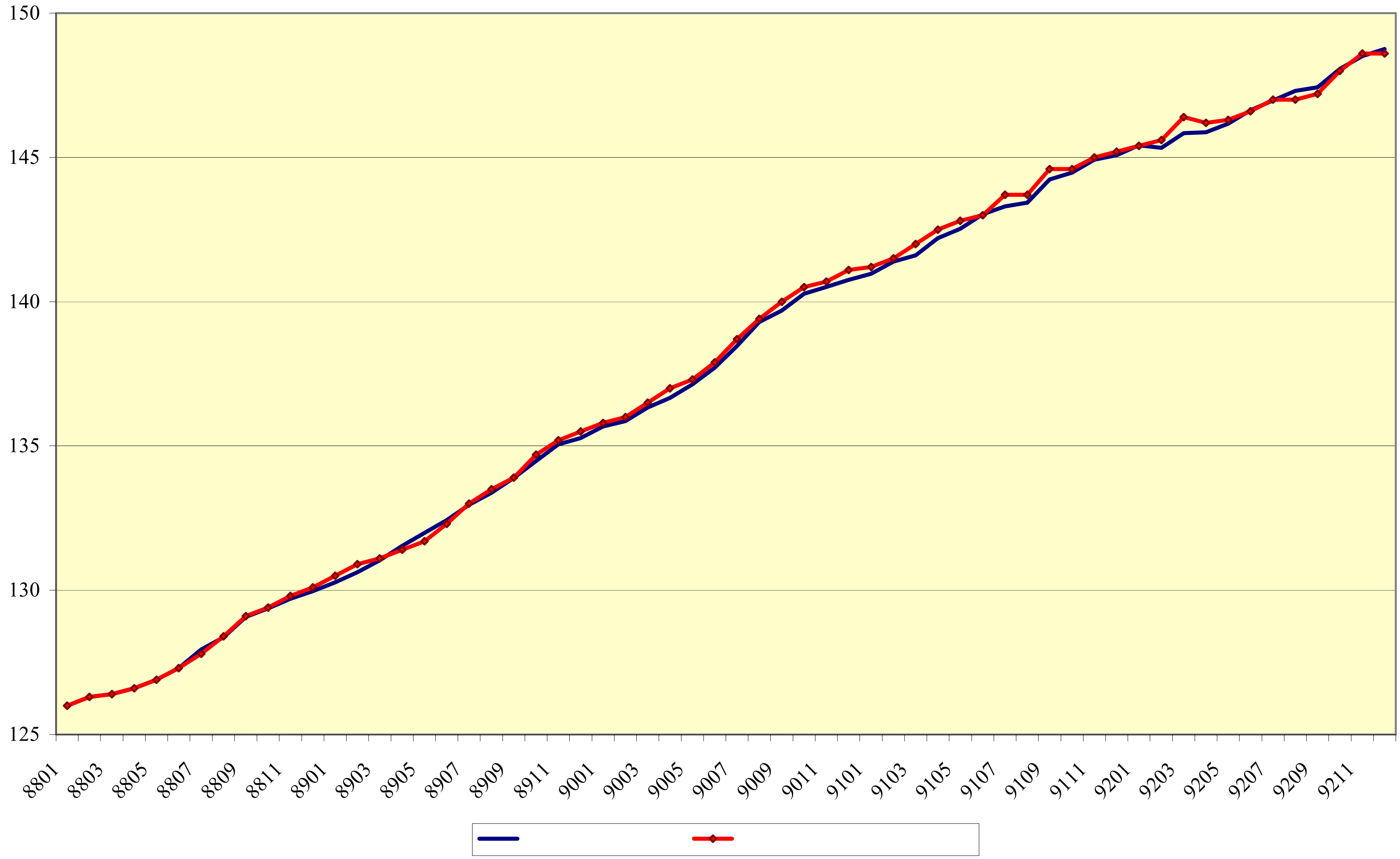

Figure 1. Comparison of Indexes based on Six-Month and One-Month Rental Increases

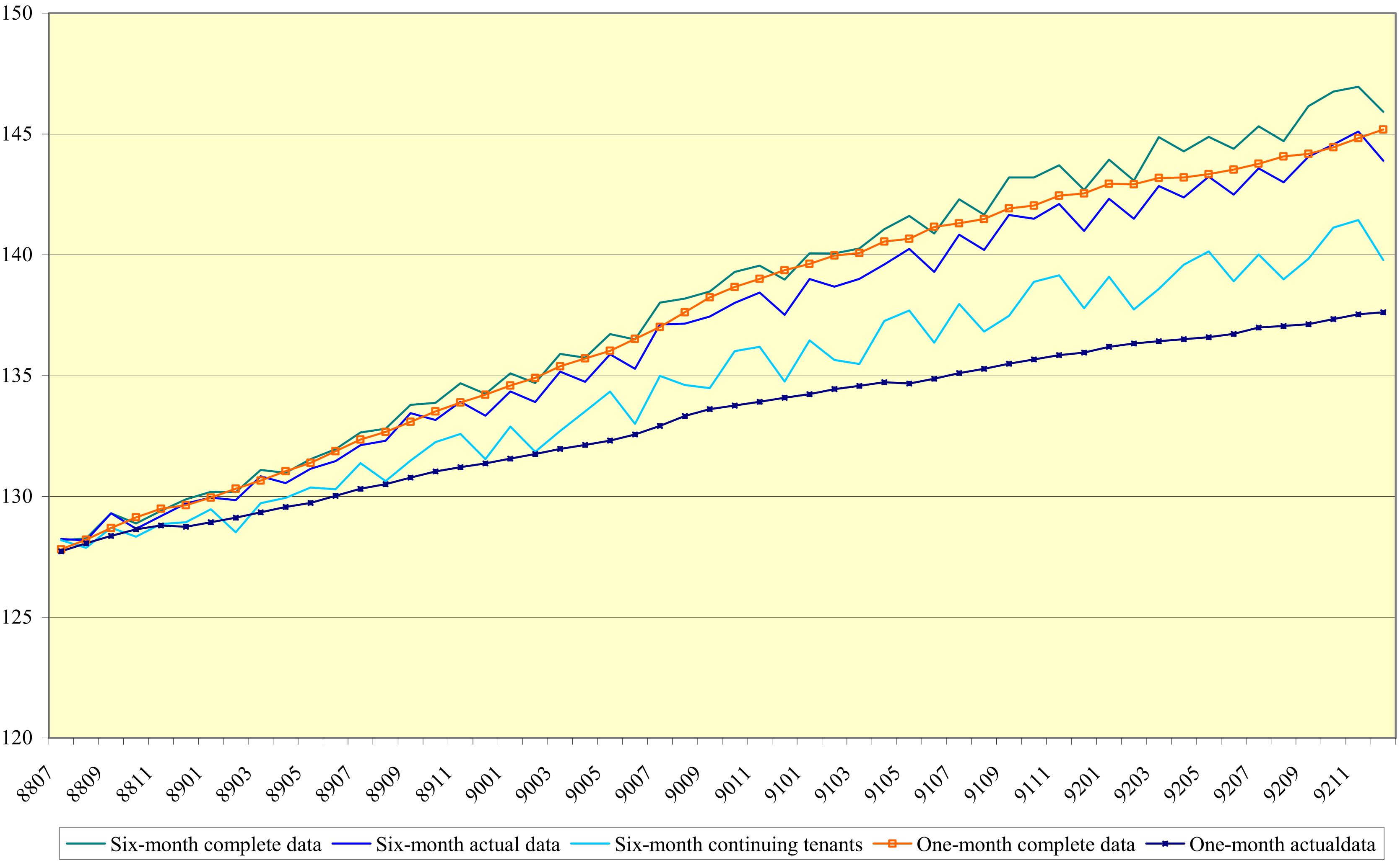

Figure 2: Price comparisons: old and revised CPI for rent with CPI excluding shelter and GDP deflator 3 year moving average inflation rates

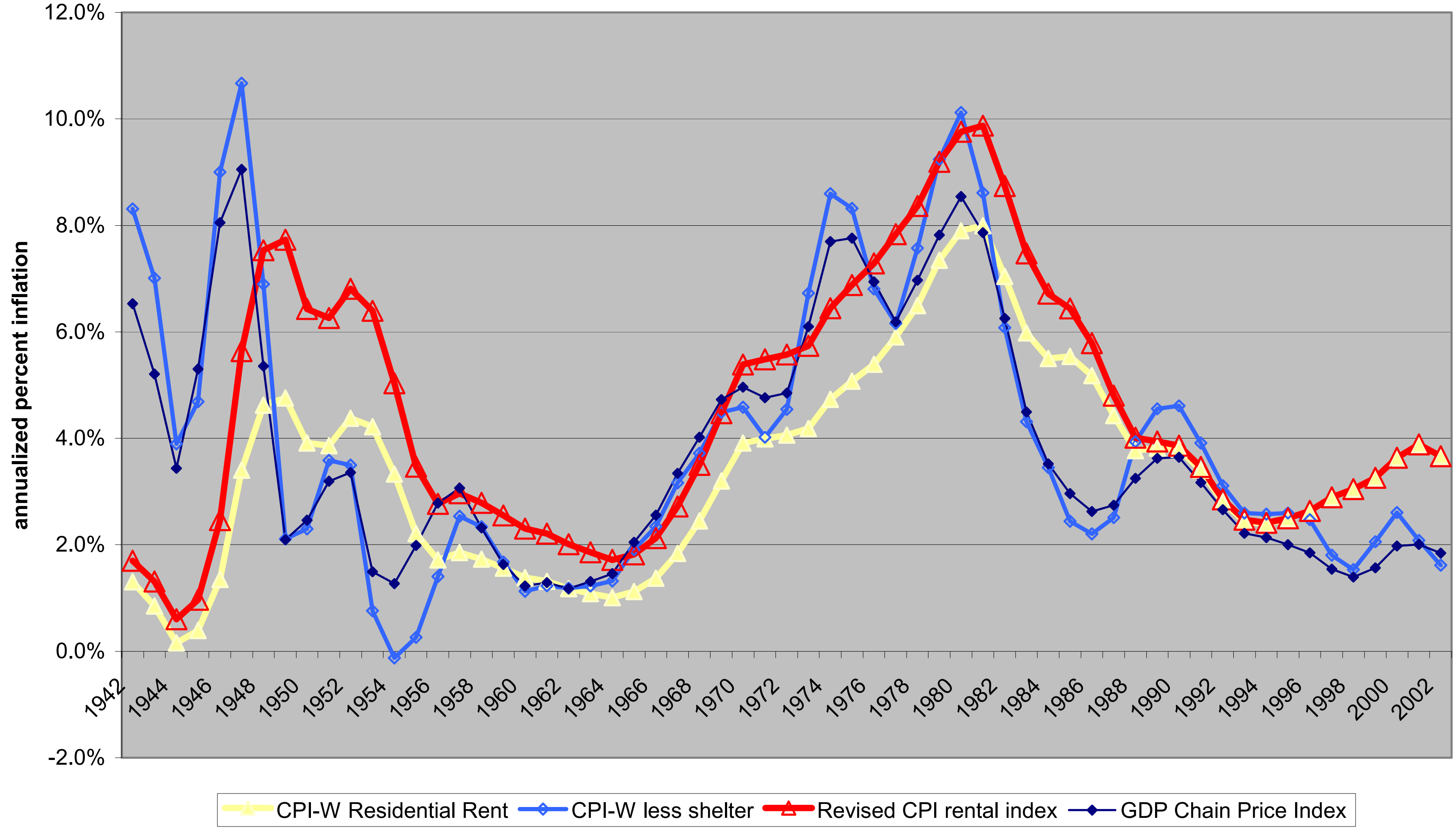

Figure 3. Housing services per unit of residential stock
Ratio, year 2000 ratio = 100