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ABSTRACT

Recent research finds that the shelter component of CPI inflation responds with a lag to movements in market rents—the rents that tenants pay when they move into a new dwelling. This paper seeks to improve our understanding of this fact. We start by identifying three sources of lags between market rents and CPI shelter: the rents of most tenants are set in long-term leases; rents are smoothed for continuing tenants who renew leases; and CPI shelter inflation is measured with rent changes over six months. We incorporate these lags in a model of shelter inflation and compare the model to monthly data since 2015, using the Zillow Observed Rent Index to measure market rents. We find that the model performs fairly well, suggesting that it may be useful for understanding and forecasting inflation.

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1 Introduction

The shelter component of the consumer price index has a weight of about 35% in the CPI. It is determined primarily by rents for dwellings, both actual rents paid by tenants and imputed rents for owner-occupied housing. Because of the large weight on shelter, changes in rents can have major effects on CPI inflation. Shelter inflation was an important factor in both the surge in inflation over 2021-2022 and the subsequent disinflation. Such experiences have led many economists to study shelter inflation and seek to predict it.

It is well-known that the CPI shelter index responds with a substantial time lag to movements in "market rents"—–the rents that tenants agree to pay when they move into a new dwelling. Because of this lag, economists often examine measures of market rents, such as indexes produced by the real-estate firms Zillow and CoreLogic, to predict the future paths of shelter and overall CPI inflation. When market-rent inflation surged in 2021, Bolhuis *et al.* (2022) predicted that shelter inflation would rise over 2022. After market-rent inflation peaked and started falling in late 2022, commentators such as Krugman (2023) predicted that shelter inflation would soon fall and push overall inflation toward the Federal Reserve's target.

A growing literature seeks to measure the lags between market rents and shelter inflation. This research, which we review below, consists primarily of atheoretical forecasting exercises using techniques from time series econometrics. This paper takes a more structural approach that brings to bear what we know about the behavior of rent setters and tenants and how the CPI shelter index is constructed. We identify the specific sources of lags between market rents and CPI shelter and seek to quantify their effects.

There are three reasons that it takes time for movements in market rents to influence the CPI shelter index:

- Most obviously, rents are usually set in long-term leases, most often for 12 months. The rent for a dwelling cannot react to a movement in market rents until the tenant's current lease ends.

- Even when the lease ends, if the tenant remains in the dwelling and signs a new lease, the rent does not adjust fully to movements in market rents. That is, landlords smooth rents for continuing tenants.

- Finally, the CPI shelter index is constructed by comparing the current rent for a given dwelling to the rent six months earlier. As a result, the monthly growth rate of the index is an average of rent growth over the previous six months.

After documenting these lags, we develop a model of rent behavior that incorporates all three of them. We take the path of market rents as exogenous and use the model to derive the implied path of CPI shelter inflation. We then compare the model's predictions to the data on shelter inflation and market rents over 2015-2025, using a measure of market rents based on the Zillow Observed Rent Index (ZORI).

The model has three key parameters. We calibrate two of them based on micro data: parameters that capture the lengths of rental leases and the frequency with which tenants move between dwellings (and therefore pay market rents). The final parameter is the rate at which rents for continuing tenants adjust to market rents when leases are renewed. This parameter is difficult to calibrate, so we treat it as a single free parameter and estimate it with our aggregate data. We find a strong degree of smoothing: when a 12-month lease is renewed, the rent adjusts only 21.3% of the way toward current market rents.

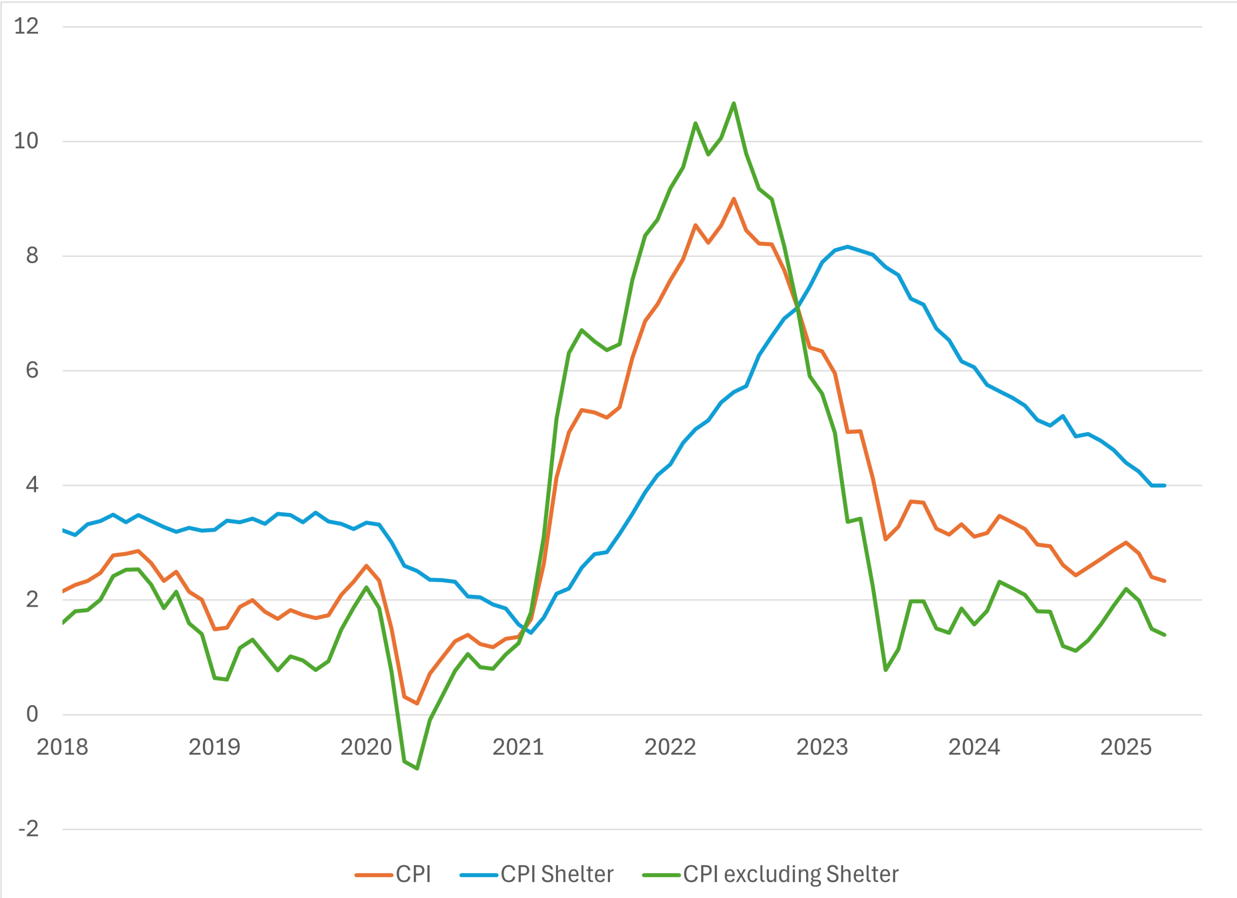
We find that our model fits the data fairly well: the predicted values of CPI shelter inflation follow the actual path of shelter inflation. In particular, the model captures the lagged responses of CPI shelter to the sharp rise in market-rent inflation in 2021 and the subsequent sharp fall.

In what follows, we first give additional background on our topic and then present and calibrate our model and compare it to the data.

2 Background

The recent interest in shelter inflation has been spurred by the inflation experience since the COVID pandemic. This section reviews this experience and the research it has generated.

Figure 1: Shelter and non-shelter inflation



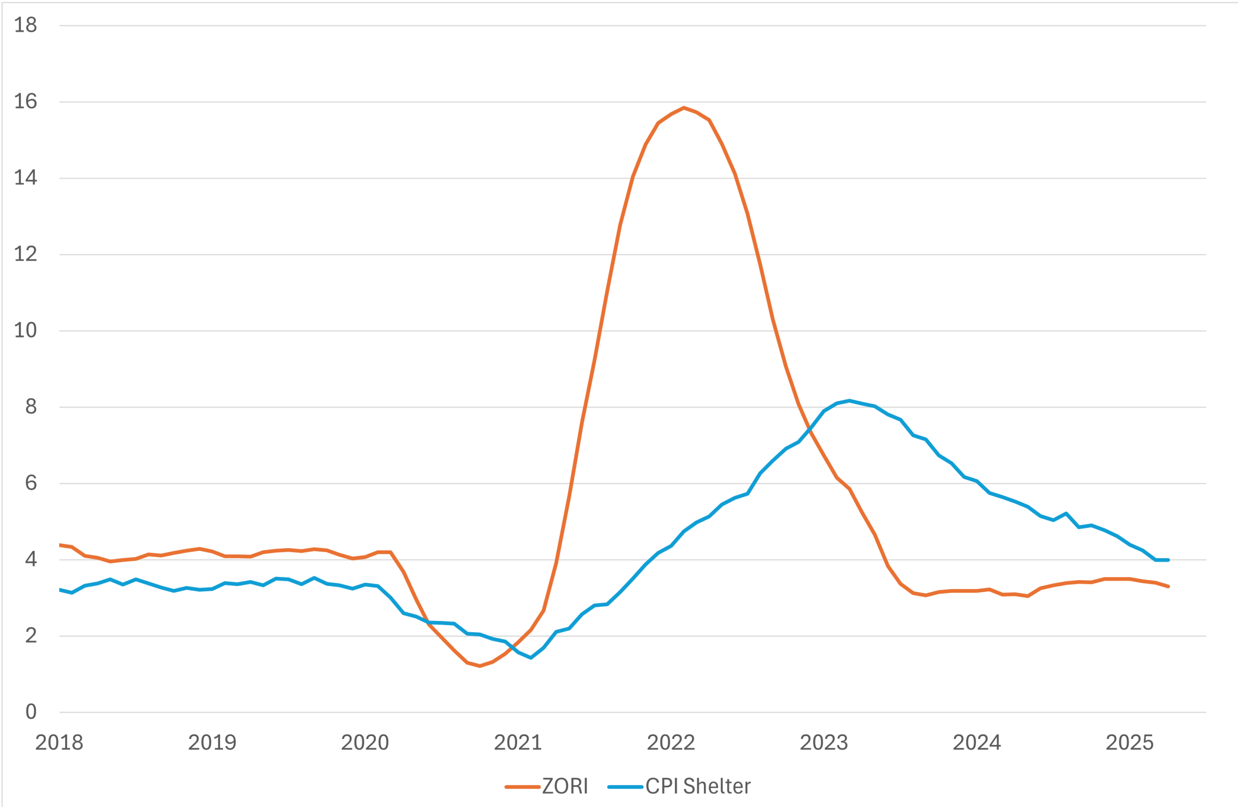
12-month inflation rates in CPI, CPI shelter, and CPI excluding shelter, 2018-2025. Source: Bureau of Labor Statistics.

2.1 The Recent History of Shelter Inflation and Market Rents

Figure 1 shows the path of the twelve-month CPI inflation rate from 2018 to the present, and also decomposes that variable into inflation in shelter and in the CPI excluding shelter. During the inflation surge of 2021 and 2022, shelter prices rose less rapidly than the rest of the CPI, which somewhat dampened the rise in overall inflation. But starting in late 2022, inflation excluding shelter fell rapidly while shelter inflation remained relatively high. For the last two years, non-shelter inflation has generally been below 2% but shelter has pulled up overall inflation. In discussing why inflation has exceeded the Federal Reserve's target, Mankiw (2024) says, "it's all about shelter."

Figure 2 compares the shelter inflation rate from Figure 1 to the growth rate in a

Figure 2: Inflation in CPI shelter and ZORI



12-month inflation rates in CPI shelter and Zillow Observed Rent Index (ZORI), 2018-2025. Source: Bureau of Labor Statistics, Zillow.

leading measure of market rents, the Zillow Observed Rent Index (ZORI). We see the well-known lags between market rents and CPI shelter. Market rent inflation fell at the onset of the pandemic, rose sharply over 2021 and early 2022, and then fell sharply. CPI shelter inflation followed this pattern in a more muted way, with peaks and troughs occurring later. Since mid-2023, market rent inflation has been stable at a low level and shelter inflation has fallen slowly toward that level.

2.2 Recent Research on Market Rents and Shelter Inflation

Researchers have long analyzed how market forces influence shelter inflation (e.g., Verbrugge (2008)), but until recently this issue was not salient to economists studying aggregate inflation. That has changed, in part because of the dramatic swings in rent inflation since the pandemic and in part because firms such as CoreLogic and Zillow have produced indexes of market rents. Many studies have used these data to explain and forecast shelter inflation.

Bolhuis *et al.* (2022) was an early contribution to this literature, which predicted that the rise in market rent inflation over 2021 would lead to higher CPI shelter inflation in 2022. Zhou & Dolmas (2021) and Lansing *et al.* (2022) also predicted the rising shelter inflation that occurred through early 2023.

After market-rent inflation peaked and started to fall, a number of studies forecasted falling shelter inflation (e.g., Cotton & O'Shea (2023); Council of Economic Advisers (2023); Kmetz *et al.* (2023)). Shelter inflation did fall over 2023-2024, although some studies were over-optimistic about the speed of decline, predicting that shelter inflation would be near its pre-pandemic level by early 2024.[1]

Forecasts in this literature are based mainly on regressions of shelter inflation on its own lags, lags of market-rent inflation, and sometimes other variables such as growth in house prices. Some work, such as Cotton & O'Shea (2023), imposes an error-correction structure in which the levels of market rents and CPI shelter converge over time. Researchers have faced the challenge of estimating a large number of parameters with data from a relatively short time period. Some studies address this problem by exploiting the variation in regional data. Some use sophisticated econometric methods; for example, Bolhuis *et al.* (2022) use elastic net regression to shrink coefficients and reduce overfitting.

The present paper complements this past research. We examine only ten years of aggregate data and do not use sophisticated econometrics, but the structure of our model yields a specification with only one free parameter to estimate.

3 Three Sources of Lags

Many economists point out CPI shelter inflation responds to market rents with a lag, but often they do not spell out the reasons. There are three distinct sources of lags, which we

[1] More recent work on shelter inflation includes Jordà & Yalcin (2024), Bianchi *et al.* (2024), Kishor (2024), and Loewenstein *et al.* (2024).

review in this section.

3.1 Long-Term Leases

The first source of lags is the most obvious. Most tenants in houses and apartments sign leases with landlords that fix their rent for a period of time. Specifically, according to work from the Bureau of Labor Statistics (Houck, 2022), about 60% of dwellings are covered by 12-month leases and 9% by leases of other lengths, with the starting dates of leases spread over the year. These facts imply that the rents for most dwellings cannot react immediately to a change in market rents and, given the prevalence of 12-month leases, it takes at least a year for market developments to transmit to the rents of all tenants.

This type of price-adjustment lag is not unique to the housing market. Many wages and salaries are fixed for 12 months at a time, and the prices of some goods and services are also reset infrequently.

3.2 Rent Smoothing in Lease Renewals

Another source of lags is less obvious. When a lease ends, the current tenant often remains in the dwelling and renews the lease. In principle, absent legal rent controls, the landlord can demand any rent to renew the lease. It appears, however, that rents in renewed leases do not respond fully to movements in market rents for new tenants. Because a tenant may remain in a dwelling for many years, renewing the lease repeatedly, this rent smoothing can greatly slow the adjustment of the average rent to market rents.

Gallin *et al.* (2024) report evidence of this effect—which they call "sticky continuing-tenant rents"—in BLS microdata. They find that the rent for a dwelling is less likely to change at all for continuing tenants than for new tenants, and that changes that do occur (both increases and decreases) are smaller on average for continuing tenants.

Few analyses of shelter inflation explicitly discuss this point, but Fed officials appear to be aware of it. In his June 2024 news conference, Chair Powell said:

> When market-based rents go up sharply, as they did when the economy re-

> opened, they went up really sharply. Those play into rollover rents [rents in new leases] much more slowly for existing tenants than they do for new tenants. And so we've found now that there are big lags.

The reasons for this smoothing of rents are not entirely clear. It may arise from fear of upsetting customers with large price changes, which slows price adjustment in many markets (Rotemberg, 2005). Gallin & Verbrugge (2019) show theoretically that stickiness in renewal rents can arise from asymmetric information about tenants' valuation of apartments.

3.3 Six-Month Rent Changes and CPI Shelter Inflation

The final source of lags is the method used by the BLS to compute the two main components of CPI shelter prices, Rent of Primary Residence (RPR) and Owners' Equivalent Rent (OER). This lag is stressed by Bolhuis *et al.* (2022).[2]

The RPR and OER indexes are derived from a monthly survey of rents for individual dwellings. The BLS surveys a given dwelling every six months: a cohort of dwellings is surveyed every January and July, another every February and August, and so on. Letting R denote either RPR or OER, the gross inflation rate in R in month t (not annualized) is measured as:

$$\pi_t^R = \frac{R_t}{R_{t-1}} = \left(\frac{r_t}{r_{t-6}}\right)^{\frac{1}{6}} \tag{1}$$

where r_t is a weighted average of rents for the dwellings surveyed at t and r_{t-6} is the average for the same dwellings at $t-6$. The OER and RPR indexes differ in the weights applied to individual dwellings, which are chosen to make the indexes representative of rental and owner-occupied properties, respectively.

Equation (1) says that the gross inflation rate in OER or RPR is the growth of an average rent over the last six months, converted to a monthly rate. Because of this definition, the monthly inflation rates for RPR and OER reflect rent inflation over six months, not just the current month.

[2]The BLS method is described on its website: `https://www.bls.gov/cpi/factsheets/owners-equivalent-rent-and-rent.htm`.

This third lag slows the adjustment of CPI shelter inflation to the average rent paid by all tenants. The two lags discussed earlier slow the adjustment of all-tenant rents to market rents for new tenants. All three factors contribute to the overall lag between CPI shelter and market rents, as we show in our model.

4 A Simple Model

Our model takes the path of market rents as exogenous and determines the path of CPI shelter inflation, given the three lags we have identified.

4.1 The Lengths and Timing of Leases

We assume that dwellings are occupied by two types of tenants: a fraction ϕ of all tenants rent month-to-month without a lease (short-term tenants), and a fraction $1-\phi$ sign 12-month leases (long-term tenants). This assumption is fairly realistic: according to Houck (2022), 91% of tenants belong to one of these categories. Our model ignores the 9% of tenants with other lease lengths (most often six months).

The signing dates of 12-month leases are distributed uniformly over the year, with 1/12 of all leases signed in each month. This assumption implies that the average rent paid in 12-month leases in month t is an average over leases signed in months $t, t-1, \ldots, t-11$. We ignore the fact that, in reality, there is some seasonal variation in the timing of leases.

Let r_t equal the average of all rents paid in month t; s_t the average of rents paid by short-term tenants in month t; and l_t the average of rents paid in 12-month leases signed in month t. Combining our assumptions about the lengths and timing of leases, the average of all rents is:

$$r_t = \phi s_t + \frac{1-\phi}{12}\sum_{i=0}^{11} l_{t-i} \tag{2}$$

4.2 Movers

In each month t, a fraction α of short-term tenants move to a new dwelling, where they continue to rent month-to-month. Movers are chosen randomly from all short-term tenants: the decision to move arrives as a Poisson process, like price adjustment in the Calvo (1983) model. In other words, the probability of moving does not depend on how long a tenant has lived in a dwelling.[3]

Among tenants with long-term leases, those whose leases do not expire in month t cannot move. Of those with expiring leases—leases signed at $t-12$—a fraction 12α move and sign a 12-month lease for a new dwelling. This group of movers, again chosen randomly, is a fraction α of all tenants with 12-month leases, so the average frequency of moving is the same for short-term and long-term renters. A tenant with an expiring 12-month lease who does not move signs a new 12-month lease for the same dwelling, generally with a new rent.

Let m_t be the market rent for new tenants. We assume that m_t is the rent for short-term tenants who move at t and also the rent in 12-month leases signed by movers at t. We let s_t^n denote the average rent of short-term tenants who do not move at t and l_t^n the average rent in 12-month leases renewed at t. Averaging across movers and non-movers, the average rent of short-term tenants is

$$s_t = \alpha m_t + (1-\alpha)s_t^n \tag{3}$$

and the average rent in 12-month leases signed at t is

$$l_t = 12\alpha m_t + (1-12\alpha)l_t^n \tag{4}$$

4.3 The Smoothing of Rents for Non-movers

Our key behavioral assumptions concern the rents paid by continuing tenants. For a short-term tenant who does not move, we assume that the rent is a weighted average of

[3]This assumption is not too far from reality: Gallin et al. (2024, Figure 4b) measure moving rates in micro data and find that they do not vary greatly with tenure in a dwelling.

the current market rent and the rent paid by the tenant in the previous month. Averaging across all short-term tenants who do not move yields:

$$s_t^n = \lambda m_t + (1-\lambda)s_{t-1},\ 0 < \lambda < 1 \tag{5}$$

where we use the fact that movers are selected randomly, so the average rent of non-movers at $t-1$ equals the average rent of all short-term tenants at $t-1$.

Equation 5 is a partial adjustment equation: rents of non-movers change by a fraction λ of the difference between market rents and past rents. Market rents have some influence on the rents of continuing tenants, but the effect is less than one-for-one (and much less according to our empirical work).

Similarly, when a 12-month lease is renewed, the new rent is an average of the current market rent and the rent in the expiring lease, which was signed at $t-12$. Averaging across non-movers:

$$l_t^n = \tilde{\lambda} m_t + (1-\tilde{\lambda})l_{t-12}, \tag{6}$$

where we assume

$$\tilde{\lambda} = 1-(1-\lambda)^{12} \tag{7}$$

Notice that $\tilde{\lambda}$ equals the cumulative adjustment of rents for continuing short-term tenants to market rents after 12 months. Our assumptions mean that the adjustment rate per unit of time is the same for short-term and long-term tenants.

4.4 Aggregate Rents

We can now derive the average rent of all tenants, r_t, as a function of current and past market rents. Substituting equation (5) for s_t^n into equation (3) leads to

$$s_t = A_s m_t + (1-A_s)s_{t-1}, \tag{8}$$

where $A_s = \alpha + (1-\alpha)\lambda$. Recursively substituting this equation into itself yields

$$s_t = A_s \sum_{i=0}^{\infty} (1-A_s)^i m_{t-i} \tag{9}$$

The average rent of all short-term tenants is an average of past market rents with weights that decline at rate $1 - A_s$.

Similarly, substituting equation (6) for l_t^n into equation (4) yields

$$l_t = A_l m_t + (1-A_l) l_{t-12} \tag{10}$$

where $A_l = 12\alpha + (1-12\alpha)\tilde{\lambda}$. Here, recursive substitution yields

$$l_t = A_l \sum_{i=0}^{\infty} (1-A_l)^i m_{t-12i} \tag{11}$$

Rents in 12-month leases signed at t are a weighted average of market rents at t, $t-12$, $t-24\ldots$.

The average of all rents, r_t, is determined by equation (2), which gives r_t in terms of s_t and lags of l_t, and equations (9) and (11) for s_t and l_t.

4.5 Inflation in CPI Shelter

The final part of our model is the link between current rents and the CPI shelter index. Recall that the main components of this index are Rent of Primary Residence and Owners' Equivalent Rent, and that the gross inflation rate for each is defined by Equation (1): $\pi_t^R = (r_t/r_{t-6})^{\frac{1}{6}}$, where r_t is an average of all rents. Here, we assume that (1) holds with R_t interpreted as the overall shelter index and with r_t determined as described above.

Notice that Equation (1) can be re-written as

$$\pi_t^R = \left[\left(\frac{r_t}{r_{t-1}}\right)\left(\frac{r_{t-1}}{r_{t-2}}\right)\cdots\left(\frac{r_{t-5}}{r_{t-6}}\right)\right]^{\frac{1}{6}} \tag{12}$$

$$= [\pi_t^r \pi_{t-1}^r \cdots \pi_{t-5}^r]^{\frac{1}{6}} \tag{13}$$

where π_t^r is the gross inflation rate in all rents in month t. Thus the inflation rate in the shelter index R_t is a geometric average of rent inflation from $t-5$ through t. This fact implies that inflation in R_t responds to market rents more slowly than inflation in current rents r_t.

The inflation rate π_t^R is a non-linear function of current and past market rents. By taking first-order approximations, we can express π_t^R as a weighted average of current and lagged inflation rates in market rents:

$$\pi_t^R \approx \sum_{i=0}^{\infty} \omega_i \pi_{t-i}^m \tag{14}$$

where $\pi_t^m = m_t/m_{t-1}$ and the weights ω_i are positive and sum to one. The Appendix derives equation (14) and expressions for the weights, which are complex because they reflect the three different lags between market rents and CPI shelter.

5 Fitting the Model to the Data

We will compare our model to the CPI data on shelter inflation and the Zillow Observed Rent Index (ZORI), a leading measure of market rents. These data have several features that make them imperfect measures of the variables in our model, which leads us to adjust both the data and the model to make them as consistent as possible.

5.1 Measuring CPI Rent Inflation

The CPI shelter index has four components. The two largest are Rent of Primary Residence (RPR) and Owner's Equivalent Rent (OER), with weights of 21.1% and 74.1% in December 2024. As described above, both of these indexes are derived by comparing rents in a given month to rents six months earlier. The other components of CPI shelter, which are measured differently, are the prices of lodging away from home (e.g., hotel rooms) and of household insurance. These components have weights of 3.6% and 1.1%, respectively.

The variable π_t^R in our model is a six-month inflation rate that matches the construction of RPR and OER. In our empirical work, our baseline measure of π_t^R is an average of the inflation rates in RPR and OER with weights proportional to their December 2024 CPI weights. In the rest of this paper, we will call this variable "CPI shelter inflation" even though two components of the official shelter index are excluded. We have also performed separate analyses of RPR inflation and OER inflation, which yield similar results because the two rent indexes move together fairly closely.

Figure 3 compares our measure of CPI shelter inflation to the official measure with all four components, at both annualized monthly rates (in Figure 3a) and 12-month rates (in Figure 3b). At the monthly frequency these series differ noticeably, with greater volatility in official shelter. This reflects the fact that the components left out of our measure, while small, can have highly volatile prices. In particular, there were huge swings in the prices of lodging away from home during the pandemic shutdown and subsequent reopening. Our model does not explain that part of official shelter inflation.

5.2 The Zillow Data

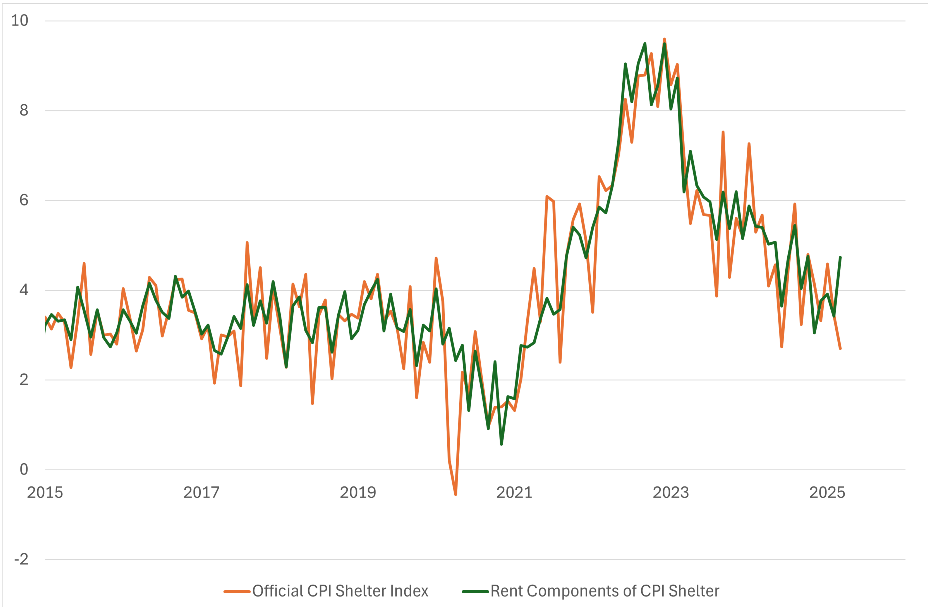
Our measure of market rents is based on the Zillow Observed Rent Index (ZORI) published by the real-estate firm Zillow and documented by Clark (2022). ZORI is a measure of average rents in Zillow's database of rents paid by new tenants. It is a monthly index and begins in January 2015.

To make its index more representative of the U.S. rental market, Zillow weights its micro observations to obtain distributions of structure types and ages of buildings that match aggregate data from the Census Bureau. However, the ZORI sample differs from the entire market in other ways that Zillow does not adjust for. In particular, the properties covered by ZORI tend to be larger and more expensive, and the index covers urban areas rather than the entire country (Adams *et al.*, 2024).

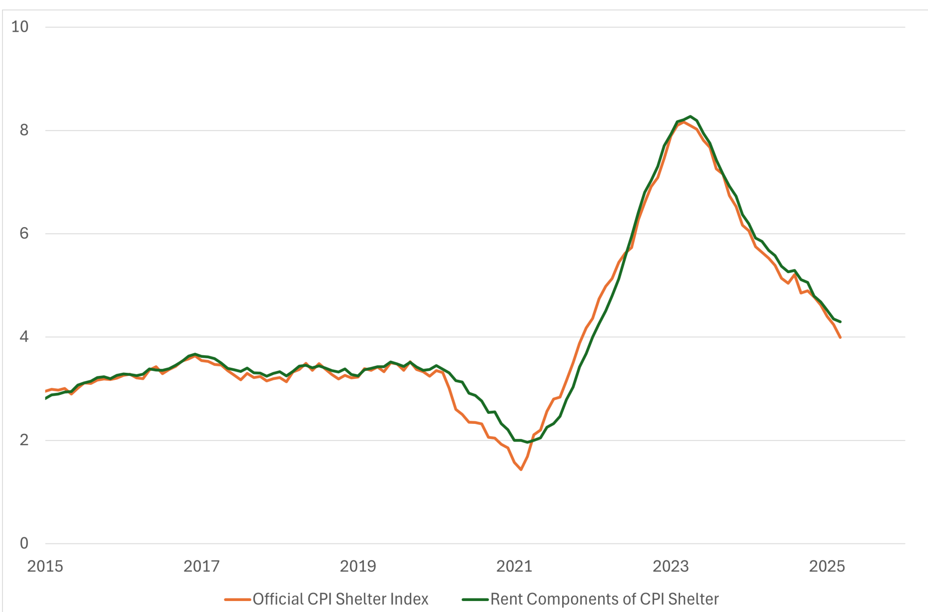
Zillow computes an average market rent each month, but the ZORI index it publishes is smoothed: it is the average of market rents over the three months from $t-2$ through t. We use the seasonally adjusted version of this series.

Figure 3: Inflation in CPI shelter and its rent components

(a) Annualized monthly inflation rates.



(b) 12-month inflation rates.



Inflation rates of official CPI shelter index and rent components of CPI shelter, 2015-2025. The rent components are a weighted average of Rent of Primary Residence (RPR) and Owners' Equivalent Rent (OER) with December 2024 weights. Source: Bureau of Labor Statistics and authors' calculations.

5.3 Accounting for Time-Averaging

The model we have developed relates monthly inflation in CPI shelter to monthly inflation in market rents. We must adjust our analysis to account for the time-averaging in our market-rent data.

Equations (2), (9) and (11) give s_t, l_t, and r_t—the average rents for short-term tenants, in new 12-month leases, and for all tenants—in terms of current and lagged market rents. It is straightforward to aggregate these equations across three months, yielding

$$\bar{r}_t = \phi \bar{s}_t + \frac{1-\phi}{12} \sum_{i=0}^{11} \bar{l}_{t-i} \tag{15}$$

$$\bar{s}_t = A_s \sum_{i=0}^{\infty} (1-A_s)^i \bar{m}_{t-i} \tag{16}$$

$$\bar{l}_t = A_l \sum_{i=0}^{\infty} (1-A_l)^i \bar{m}_{t-12i} \tag{17}$$

where a bar over a letter indicates a three-month moving average, e.g., $\bar{r}_t = \frac{1}{3}(r_t + r_{t-1} + r_{t-2})$ and $\bar{m}_t = \frac{1}{3}(m_t + m_{t-1} + m_{t-2})$. We will use the ZORI market-rent data (with an adjustment described below) to measure $\bar{m}_t$.

We still seek to explain CPI shelter inflation, π_t^R, at the monthly frequency. Our model does not determine an exact relation between this variable and the series for $\bar{m}_t$, but we can derive a first-order approximation. We first linearize equation (13):

$$\pi_t^R \approx \frac{1}{6}(\pi_t^r + \pi_{t-1}^r + \cdots + \pi_{t-5}^r) \tag{18}$$

This approximation of π_t^R replaces the geometric average of rent inflation from $t-5$ through t with the arithmetic average.

Next, the gross inflation rate in $\bar{r}_t$ is

$$\pi_t^{\bar{r}} = \frac{\bar{r}_t}{\bar{r}_{t-1}} = \frac{r_t + r_{t-1} + r_{t-2}}{r_{t-1} + r_{t-2} + r_{t-3}} \tag{19}$$

Another first-order approximation yields

$$\pi_t^{\bar{r}} \approx \frac{1}{3}(\pi_t^r + \pi_{t-1}^r + \pi_{t-2}^r) \tag{20}$$

That is, the inflation rate in the three-month average $\bar{r}_t$ is approximately the three-month average of inflation in r_t. Equation (20) also implies

$$\pi_{t-3}^{\bar{r}} \approx \frac{1}{3}(\pi_{t-3}^r + \pi_{t-4}^r + \pi_{t-5}^r) \tag{21}$$

Finally, combining equations (18), (20), and (21):

$$\pi_t^R \approx \frac{1}{2}(\pi_t^{\bar{r}} + \pi_{t-3}^{\bar{r}}) \tag{22}$$

The inflation rate π_t^R is the average of inflation in $\bar{r}_t$ (which depends on π^r from t through $t-2$) and inflation in $\bar{r}_{t-3}$ (which depends on π^r from $t-3$ through $t-5$).

Equation (22) and the equations that determine $\bar{r}_t$ ((15)—(17)) determine π_t^R in terms of lags of $\bar{m}_t$. Our empirical work examines the fit of these equations.

5.4 Differences in Average Inflation

In our model, CPI shelter inflation is a weighted average of past market-rent inflation (Equation (14)). In a steady state, shelter inflation and market-rent inflation are constant at the same level. These results depend, however, on the implicit assumption that market rents and CPI shelter are measured for the same universe of dwellings. As noted above, the dwellings in the ZORI data on market rents are on average larger, more expensive, and more urban than those in the survey underlying the CPI. For our analysis of inflation rates, it does not matter if the average *levels* of rents differ, but it does matter if there are changes over time in the relative price of the two sets of dwellings. In that case, CPI shelter inflation may be systematically higher or lower than ZORI inflation.[4]

[4] Rent inflation can differ significantly for different types of dwellings. For example, from January 2015 through January 2025, Zillow reports that annual market-rent inflation for single-family and multi-family properties averaged 5.8 percent and 4.4 percent, respectively.

To address this issue, we allow a trend in the relative price of dwellings in the CPI and ZORI samples. We interpret $\bar{m}_t$ as the three-month average of market rents in the CPI sample. Letting $\bar{z}_t$ denote the three-month average of rents in the ZORI sample—the variable that Zillow reports—we assume that

$$\bar{m}_t = \chi^t \bar{z}_t \tag{23}$$

where χ is a constant. Equivalently, the gross inflation rate $\pi_t^{\bar{m}}$ equals $\chi \pi_t^{\bar{z}}$. We use this equation to derive a series for $\bar{m}_t$ from the data on $\bar{z}_t$, given an assumed value of χ.

To calibrate χ, we use the model's property that shelter inflation and market-rent inflation are equal in steady state. As we see in Figure 4a, the period from January 2015 (when the ZORI data are first available) to January 2020 (the eve of the pandemic) looks fairly close to a steady state: the inflation rates in both CPI shelter and the ZORI index stay close to their average levels, which are 3.39 percent and 4.22 percent, respectively. We therefore choose χ to make the average level of $\pi_t^{\bar{m}}$ over this period equal the average of shelter inflation π_t^R. This implies $\chi = 0.9993344$.

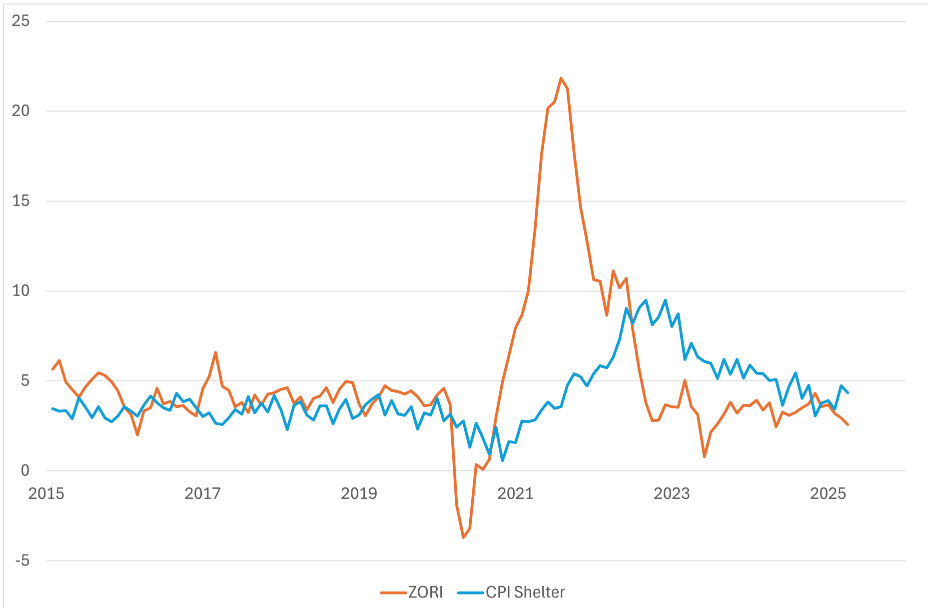
Figure 4b adds our measure of $\pi_t^{\bar{m}}$ to the series in Figure 4a. Our adjustment of the ZORI inflation rate shifts our measure of market-rent inflation down by a constant. We interpret this adjustment as correcting for a rising relative price of Zillow dwellings.

For the second half of our sample, from 2020 to the present, rental markets were far from a steady state. Therefore, for that period we do *not* assume equality of average inflation in CPI shelter and market rents. For our calibration of χ, average annual inflation after January 2020 is somewhat lower for CPI shelter (4.87 percent) than for market rents (5.08 percent). Our interpretation is that the CPI shelter index has not yet adjusted fully to the surge in market rents in 2022.

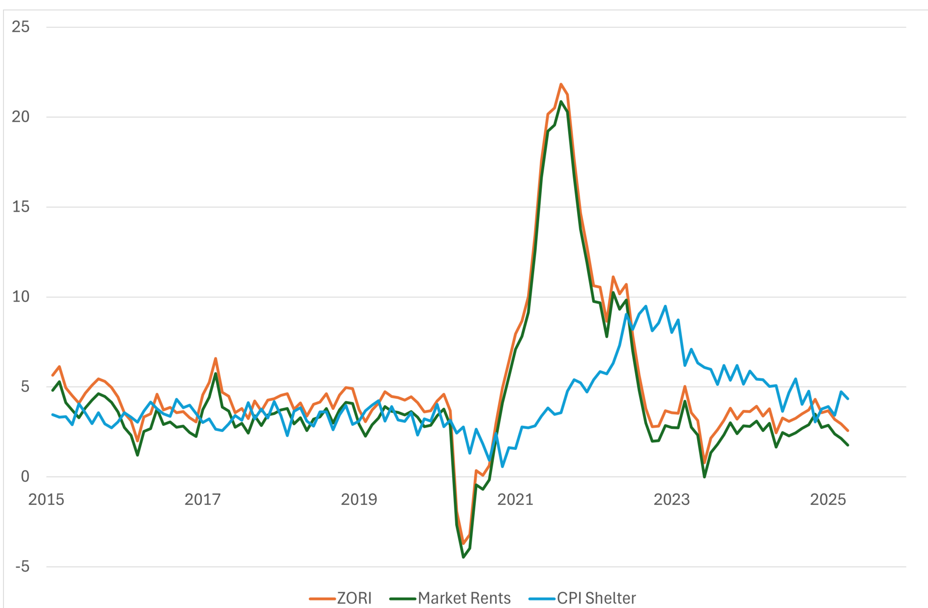
A caveat is that our analysis assumes the trend in the relative price of Zillow and CPI dwellings, which we measure over 2015-2020, continued over 2020-2025. If the trend actually shifted after 2020, that introduces error in our measure of market-rent inflation.

Figure 4: Inflation in CPI shelter, ZORI, and market rents

(a) ZORI and CPI shelter.



(b) ZORI, market rents, and CPI shelter.



Monthly annualized inflation rates of ZORI $\pi_t^{\bar{z}}$, market rents $\pi_t^{\bar{m}}$, and CPI shelter π_t^R. Our measure of market rents is derived from equation (23) with $\chi = 0.9993344$. Source: Bureau of Labor Statistics, Zillow, and authors' calculations.

5.5 Market Rents Before 2015

The ZORI data underlying our market-rent measure $\bar{m}_t$ are only available starting in January 2015. This poses a problem for explaining CPI shelter inflation, even after 2015, because that variable depends on long lags of market rents. To compare our model to the data, we need to make some assumption about market rents before 2015.

We simply assume that, before 2015, monthly inflation in $\bar{m}_t$ equals monthly inflation in CPI shelter:

$$\pi_t^{\bar{m}} = \pi_t^R \text{ for } t \leq 2015:M1 \tag{24}$$

With this assumption, we can use the data on CPI shelter inflation to extrapolate the $\bar{m}_t$ series backwards from January 2015.

This assumption is reasonable if we assume that the approximate steady state with $\pi_t^{\bar{m}}$ close to π_t^R extends backwards from 2015 for several years. Nonetheless, our crude imputation of market rents means we must be cautious in applying our model to the years right after 2015, when market rents from 2014 and earlier have large weights in our equation for shelter inflation. The model is more reliable for the pandemic and post-pandemic periods, because by 2020 the weights on market rents before 2015 are small. (In the empirical work below, we find that lags of market-rent inflation beyond five years have total weights below 0.084.)

5.6 Truncation of Lags

We make one other minor adjustment to the model: we truncate the infinite lags of market rents in our equations at 240 months. We adjust the coefficients on the lags so that they still sum to one. Specifically, we replace the equations for $\bar{s}_t$ and $\bar{l}_t$ ((16) and (17)) with

$$\bar{s}_t = \frac{A_s}{1-(1-A_s)^{240}} \sum_{i=0}^{239} (1-A_s)^i \bar{m}_{t-i} \tag{25}$$

$$\bar{l}_t = \frac{A_l}{1-(1-A_l)^{20}} \sum_{i=0}^{19} (1-A_l)^i \bar{m}_{t-12i} \tag{26}$$

This approximation is innocuous because lags beyond 240 have very small weights.

6 Parameter Values and the Implied Lag Structure

The model has three parameters. We calibrate two of them based on BLS studies of micro data: ϕ, the fraction of tenants who rent month-to-month without a long-term lease; and α, the fraction of tenants who move each month. The third parameter is λ, the monthly rate at which rents for continuing tenants adjust toward market rents. We have not found a good way to calibrate λ, so we treat it as a free parameter and estimate it with our aggregate data.

6.1 Short-Term Tenants and Moves Between Dwellings

We calibrate ϕ, the fraction of dwellings rented month-to-month, based on the BLS Housing Survey (Houck, 2022). As noted above, that study reports that 59.6% of rental dwellings have 12-month leases, 8.6% have leases of other lengths—a category that our model ignores—and 31.8% are rented month-to-month. We calibrate ϕ as the fraction of month-to-month rentals and 12-month leases that are month-to-month: $\phi = (31.8)/(31.8+59.6) = 0.348$.

We calibrate α, the fraction of tenants who move each month, using Gallin *et al.* (2024)'s analysis of BLS data. For the period 2013-2024, Gallin et al. report that about 20% of tenants at a point in time move out of their dwelling within the next 12 months. Under our assumption that moves follow a Poisson process, the fraction who move within 12 months is $1-(1-\alpha)^{12}$. Setting this expression equal to 0.2 yields $\alpha = 0.018$.[5]

6.2 The Adjustment of Rents for Continuing Tenants

The parameter λ, the rate at which rents for continuing tenants adjust to market rents, is difficult to measure directly. There is strong evidence that rents in renewed leases

[5] See Figure 4b in Gallin et al., which shows that the fractions who move for different tenures in a dwelling are clustered around 0.2.

are smoothed relative to market rents, but we have not found estimates of the degree of smoothing.

We therefore treat λ as a free parameter and choose it to produce the best fit of our model to the data. Specifically, we choose λ to minimize the sum of squared differences between the non-annualized monthly inflation rate in CPI shelter and the rate predicted by the model, given our calibration of α and ϕ.

We perform this exercise using actual and predicted inflation rates from 2018 to the present, leaving out the first three years for which data on market rents are available. The reason is that, as discussed above, our imputation of market rents before 2015 could make the model unreliable for explaining shelter inflation close to 2015. (That said, our results do not change materially if we calibrate λ based on inflation rates starting in 2015.)

Our estimate of λ is 0.0197. This implies that $\tilde{\lambda}$, the annual adjustment rate, is 0.2128. Over a year, the rents of continuing tenants adjust about 21.3 percent of the way from their past levels to current market rents.

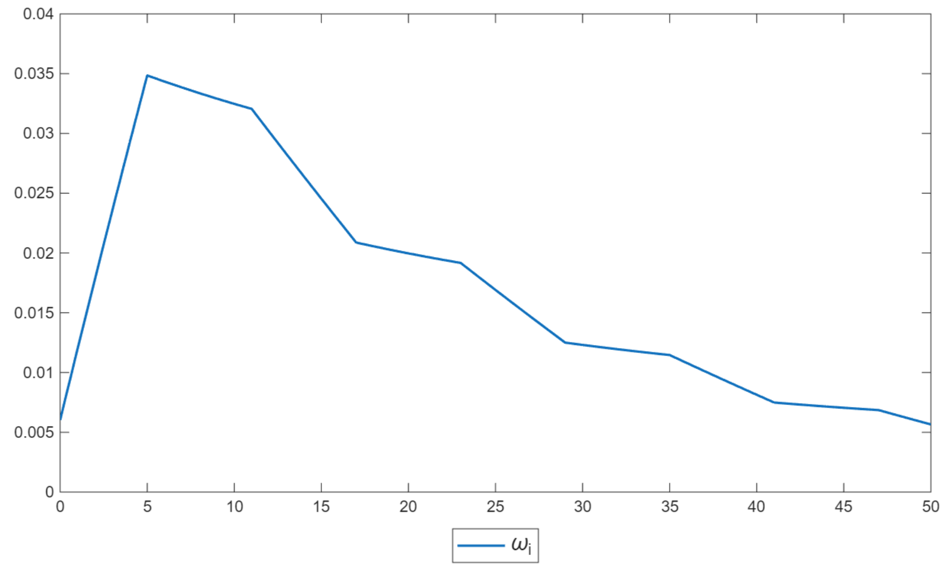
We hope that future research with BLS micro data will help us to calibrate λ. For example, one might estimate the response of rents in renewed leases to the "rent gap" analyzed by Gallin *et al.* (2024)—the difference between market rents and rents in existing leases. Our model will gain credibility if it can fit the data when all of its parameters are calibrated with independent micro evidence.

6.3 The Overall Lags Between CPI Shelter and Market Rents

In our model, the shelter inflation rate π_t^R is (to first order) a weighted average of current and past inflation rates in market rents (Equation (14)). The Appendix derives formulas for the lag coefficients ω_i in terms of ϕ, α, and λ. Now that we have values for these parameters, we can see what lag structure they imply.

Figure 5 shows the coefficients on lags 0 to 50 of π_t^m. The value of ω_0—the contemporaneous effect of market-rent inflation on shelter inflation—is only 0.006. The coefficients rise through the fifth lag, reflecting the fact that CPI shelter inflation depends on rent inflation over six months. The coefficients peak at 0.035 at the fifth lag and then decline monotonically. The slope of the lag structure shifts at lags 12, 18, 24, ..., which reflects

Figure 5: CPI shelter inflation: Coefficients on lags of market rent inflation



Coefficients in reduced-form equation for CPI shelter inflation: $\pi_t^R = \sum_{i=0}^{\infty} \omega_i \pi_{t-i}^m$. Source: Authors' calculations.

the six-month averaging in CPI shelter and the 12-month term of leases.

These results mean that it takes years for CPI shelter inflation to adjust fully to movements in market rents. The cumulated lag coefficients through 12, 24, and 36 months are 0.36, 0.61, and 0.76, respectively. The average lag in equation (14), defined as the sum of $i\omega_i$, is 26.3.

7 Model Fit and Forecasts

Here we examine the fit of our model and its implications for future shelter inflation.

7.1 Actual vs. Fitted Values of CPI Shelter Inflation

Figure 6 compares the actual path of CPI shelter inflation to fitted values from our model, both annualized monthly rates and 12-month rates. Despite the model's simplifications of reality, it captures the movements in shelter inflation fairly well. Actual and fitted values move together, following market-rent inflation with a lag.

Actual and fitted shelter inflation differ somewhat in late 2022 and early 2023. Actual 12-month inflation peaks at 8.3% in April 2023, while the fitted values peak somewhat earlier (in December 2022) and at a lower level (7.4%).

7.2 The Importance of Renewal-Rent Smoothing

In our model, rents in renewed leases and rents for continuing short-term tenants adjust slowly to movements in market rents. This feature of the model is essential for fitting the data. We can see this point by computing the fitted values for CPI shelter inflation with the parameter λ set equal to one, which means that rents in renewed leases and for continuing short-term tenants equal market rents. We keep the parameters ϕ and α at their baseline values.

Figure 7 shows the fitted values for monthly and 12-month inflation with this change in calibration. The model still predicts that CPI shelter inflation lags market-rent inflation because of long-term leases and the construction of CPI shelter inflation from six-month rent changes. However, the predicted lags are much shorter than before: with $\lambda = 1$, the fitted values of shelter inflation respond much more strongly than actual shelter inflation to the 2021 surge in market rents, and then fall more quickly once the surge subsides.

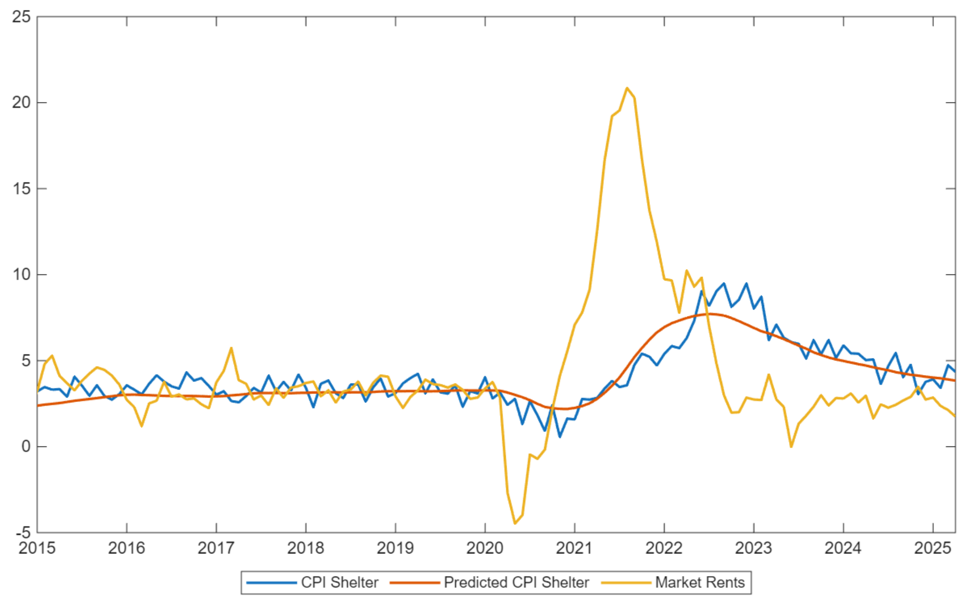
7.3 Conditional Forecasts

Having applied our model to past data, it is natural to ask what it implies for the future. Going forward, CPI shelter inflation will depend on what happens to market-rent inflation, which we will not try to predict. We can, however, predict shelter inflation conditional on a given path of market rents.

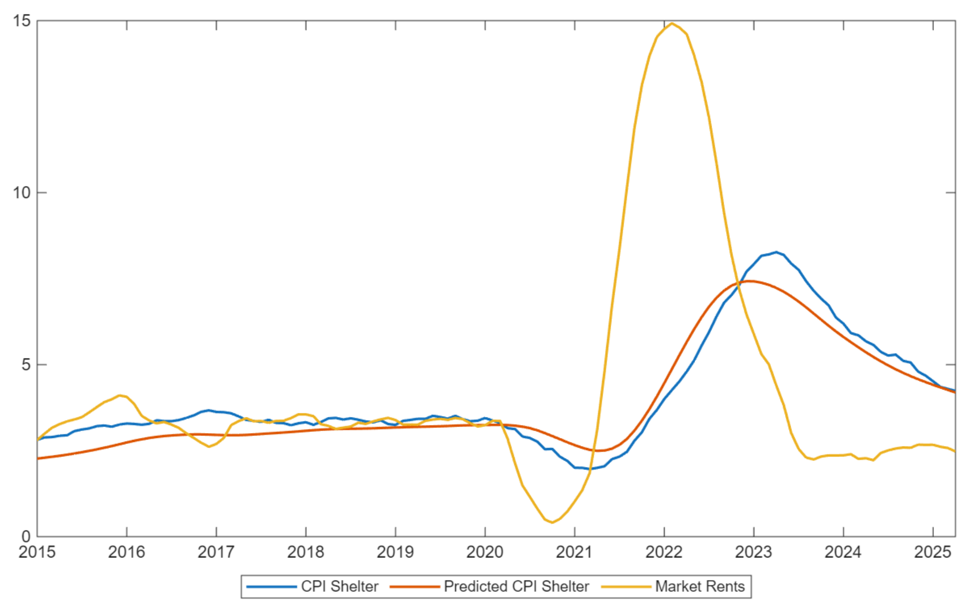
Since 2023, market-rent inflation has stabilized at a level a bit below its pre-pandemic level. We assume that this situation continues; specifically, we assume that market rent inflation starting in May 2025 is constant at an annual rate of 2.47%, which is the rate over the twelve months ending in April 2025.

Figure 6: Predicted and actual inflation rates of CPI shelter

(a) Annualized monthly inflation rates.



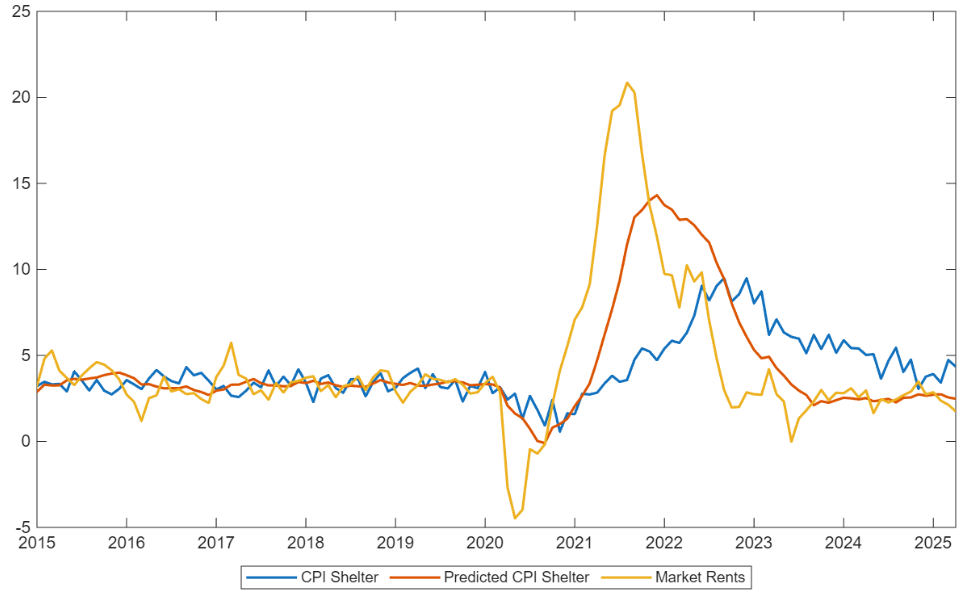
(b) 12-month inflation rates.



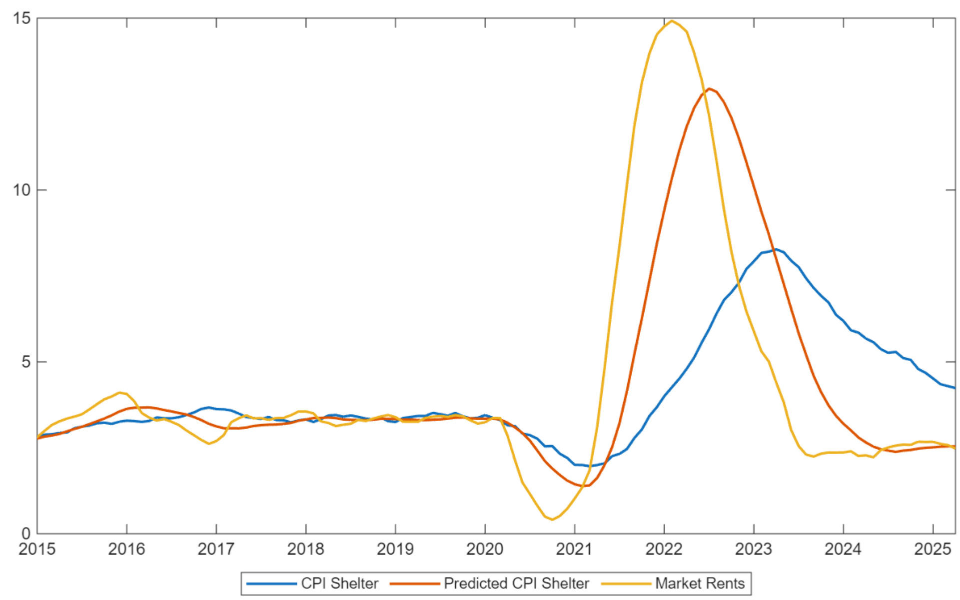
Inflation rates of market rents $\pi_t^{\bar{m}}$, CPI shelter π_t^R, and predicted CPI shelter. Source: Bureau of Labor Statistics, Zillow, and authors' calculations.

Figure 7: Predicted and actual inflation rates with no rent smoothing in renewed leases

(a) Annualized monthly inflation rates.



(b) 12-month inflation rates.



Inflation rates of market rents $\pi_t^{\bar{m}}$, CPI shelter π_t^R, and predicted CPI shelter, assuming $\lambda = 1$. Source: Bureau of Labor Statistics, Zillow, and authors' calculations.

Figure 8 shows the assumed path of market-rent inflation and the implied path of CPI shelter inflation through 2030. Not surprisingly, shelter inflation moves toward market-rent inflation over the next several years. Predicted 12-month shelter inflation is 3.7% in December 2025, 3.2% in December 2026, and 2.9% in December 2027.

8 Conclusion

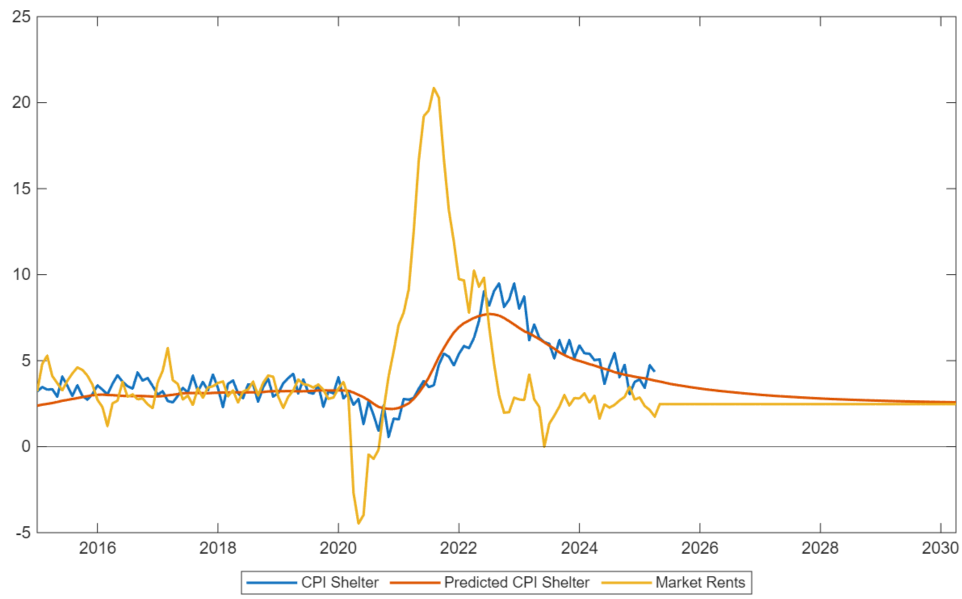
This paper models the relationship between CPI shelter inflation and market rents for new tenants. The model incorporates three reasons that the CPI shelter index lags behind market rents: long-term leases, smoothing of rents when leases are renewed, and the measurement of shelter inflation with six-month rent changes. We find that the model's predictions match the data fairly well; in particular, the model captures the lagged and dampened responses of shelter inflation to the post-pandemic surge and then retreat of market-rent inflation.

As this paper is completed, the level of market-rent inflation has been steady for two years and CPI shelter inflation is converging to that level. The next time market-rent inflation changes significantly, CPI shelter will again respond with a lag. We hope our model will prove useful for understanding such an episode.

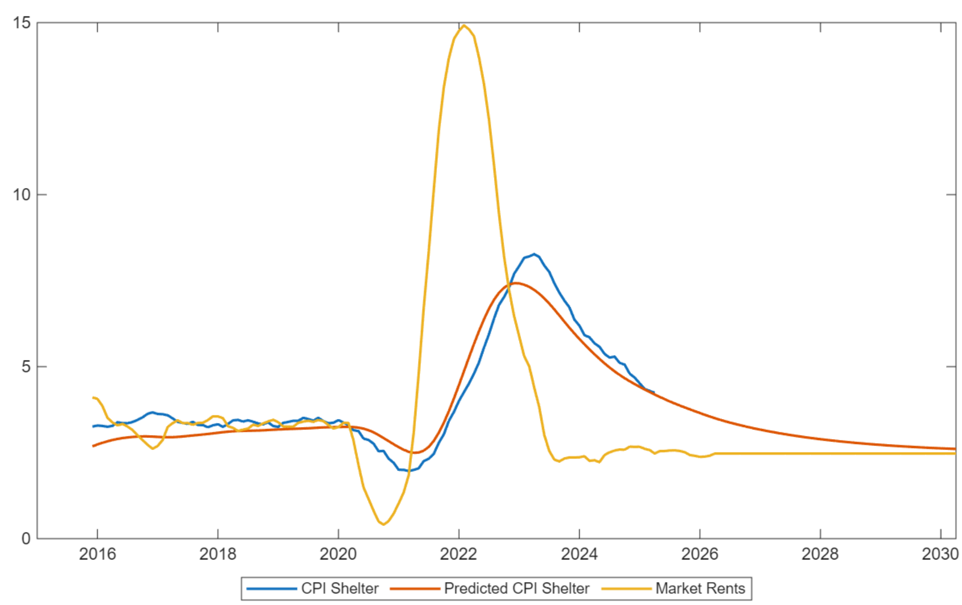
We calibrate our model with micro evidence on rental-lease lengths and the frequency of moves between dwellings. It is difficult, however, to calibrate one key parameter: the degree of rent smoothing when leases are renewed. In this paper, we estimate this parameter with the aggregate data on market rents and CPI shelter. Future research might measure renewal-rent smoothing with micro data such as the BLS rent survey.

Figure 8: Forecasts of CPI shelter inflation

(a) Annualized monthly inflation rates.



(b) 12-month inflation rates.



Inflation rates of market rents $\pi_t^{\bar{m}}$, CPI shelter π_t^R, and predicted CPI shelter, forecasted to April 2030. We assume market rent inflation is 2.47% starting in May 2025. Source: Bureau of Labor Statistics, Zillow, and authors' calculations.

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A The Reduced-Form Relation Between CPI Shelter Inflation and Market Rent Inflation

Here we show that CPI shelter inflation in our model can be written approximately as a weighted sum of current and past market-rent inflation, and derive the weights.

Equation (9) gives short-term rents s_t in terms of current and lagged market rents. We can rewrite this equation as:

$$s_t = \sum_{i=0}^{\infty} \omega_i^s m_{t-i} \tag{27}$$

$$\text{where } \omega_i^s = A_s(1-A_s)^i$$

and $A_s = \alpha + (1-\alpha)\lambda$. Similarly, we can rewrite equation (11) for rents in new leases, l_t, as:

$$l_t = \sum_{i=0}^{\infty} \omega_i^l m_{t-12i} \tag{28}$$

$$\text{where } \omega_i^l = A_l(1-A_l)^i$$

and $A_l = 12\alpha + (1-12\alpha)\tilde{\lambda}$. We can also express l_{t-j} as:

$$l_{t-j} = \sum_{i=0}^{\infty} \omega_i^l m_{t-12i-j} \tag{29}$$

We let l_t^{sum} denote the 12-period sum of l_{t-j}:

$$l_t^{sum} = \sum_{j=0}^{11} l_{t-j} \tag{30}$$

Combining equations (29) and (30), we get:

$$l_t^{sum} = \sum_{i=0}^{\infty} \omega_i^{lsum} m_{t-i} \tag{31}$$

where

$$\omega_i^{lsum} = \begin{cases} \omega_0^l & i = 0, \ldots, 11 \\ \omega_1^l & i = 12, \ldots, 23 \\ \omega_2^l & i = 24, \ldots, 35 \\ \vdots & \vdots \end{cases} \tag{32}$$

Notice that the levels of m_{t-i} from $i = 0$ to $i = 11$ each have a coefficient of ω_0^l in the equation for l_t^{sum}, because each of these terms has a coefficient of ω_0^l in the equation for l_{t-j} for some j between 0 and 11. Similarly, the levels of m_{t-i} from $i = 12$ to $i = 23$ each have a coefficient of ω_1^l, and so on. Equation (32) can be written more compactly as:

$$\omega_i^{lsum} = \omega_{\lfloor i/12 \rfloor}^l \tag{33}$$

where $\lfloor x \rfloor$ is the floor function of x.

Next, recalling the definition of r_t:

$$r_t = \phi s_t + \left(\frac{1-\phi}{12}\right) l_t^{sum}, \tag{34}$$

we can substitute (27) and (31), which yields

$$r_t = \sum_{i=0}^{\infty} \omega_i^r m_{t-i} \tag{35}$$

$$\text{where } \omega_i^r = \phi \omega_i^s + \left(\frac{1-\phi}{12}\right) \omega_i^{lsum} \tag{36}$$

Replacing terms, we can express ω_i^r as:

$$\omega_i^r = \phi A_s (1 - A_s)^i + \left(\frac{1-\phi}{12}\right) A_l (1 - A_l)^{\lfloor i/12 \rfloor} \tag{37}$$

Linearizing around a steady state with zero inflation, we can approximate the inflation rate of r_t, π_t^r, as:

$$\pi_t^r \approx \sum_{i=0}^{\infty} \omega_i^r \pi_{t-i}^m \tag{38}$$

Finally, recall the relationship between the inflation rate of R_t, π_t^R, and π_t^r:

$$\pi_t^R \approx \frac{1}{6}\sum_{j=0}^{5} \pi_{t-j}^r \tag{39}$$

Combining (38) and (39), we can approximate π_t^R with:

$$\pi_t^R \approx \sum_{i=0}^{\infty} \omega_i \pi_{t-i}^m \tag{40}$$

$$\text{where } \omega_i = \frac{1}{6}\sum_{j=0}^{5} \omega_{i-j}^r \tag{41}$$

and we define $\omega_{i-j}^r = 0$ for $i < j$. Notice that the coefficient ω_i on π_{t-i}^m reflects the effects of that term through rent inflation π^r from $t-5$ to t.