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Can Measurement Error Explain Slow Productivity Growth in Construction?

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Of all major industries, construction is the only one to have registered negative average productivity growth since 1987. One might suspect measurement error to have biased growth downward since the deflators for this sector, which are used to translate nominal construction spending into the real quantity of structures, have risen much faster than those for other sectors. We find evidence of an upward bias in these deflators related to unobserved improvements in structure quality, but the magnitude is not large enough to alter the view that construction-sector productivity growth has been weak. We also find only small contributions from other potential sources of measurement error. We conclude that productivity growth may well have been quite low in construction, even if it has not been as low as implied by official statistics.

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1. Introduction

According to data published by the Bureau of Labor Statistics, productivity growth in the construction industry has been the slowest among all of the major industry categories since at least 1987, when the current estimates begin.[1] Table 1 shows that productivity growth was actually negative on average for the construction industry over the 1987 to 2019 period, whereas it averaged at least 1 percent per year in all other major industries.[2] Figure 1 shows slow average growth is not due to a particular time period but was quite consistent from 1987 to 2019. Although the gap between the construction industry and others diminished post-2015, this narrowing was only because productivity growth slowed in other industries, not because productivity growth picked up in construction. This phenomenon is not unique to the period since 1987. Research based on unpublished BLS data and other sources has shown that productivity growth in the construction industry slowed relative to other industries in the 1970s and has remained relatively low since then (Stokes 1981, Allen 1985, Teicholz 2013, Goolsbee and Syverson 2022). Slow productivity growth has implications for housing affordability because increases in productivity could have allowed for the construction of more, higher-quality structures at a lower cost, helping to mitigate the growing imbalance between housing supply and housing demand over this period.

Is it possible that productivity growth could truly have been so sluggish for the past 50 years? A number of construction methods have changed in a way that should have increased output per labor hour. For example, nail guns became widely available in the 1980s, reducing the cost of installing nails by about half (Sichel 2022). A growing fraction of inputs for industrial construction have become prefabricated off-site, allowing for better returns to scale (Haas et. al. 1999, Teicholz 2013). And advances in information technology since the 1980s have provided the potential for efficiency gains throughout the design and management process, such as architectural design software and better communication across disperse construction sites. Moreover, growth in the capital stock in the sector has been on par or slightly exceeded that of the rest of the economy (Goolsbee and Syverson 2022). That said, labor-saving innovations like the ones listed above could have been somewhat modest. Also, these innovations may have been offset by other factors. For example, regulations related to zoning and building codes may have increased the time spent waiting for approvals and made the construction process longer and more complex.

If the construction sector really has experienced productivity growth over the past three decades or more, then the lack of increase in the official statistics would be due to measurement error. Productivity is defined as the quantity of goods or services produced per labor input, so on the broadest scale, measurement error could be found in the measurement of quantity produced or the measurement of labor input. For the construction sector, the BLS measures quantity produced as the total nominal value of structures built in a variety of subsectors divided by price deflators specific to those subsectors. Figure 2 shows nominal output divided by labor input by major industry category. In this case, the construction industry no longer appears to be an outlier relative to other industries. This

[1] Estimates of productivity growth by industry can be found at https://www.bls.gov/productivity/

[2] We do not discuss data post-2019 because of concerns about measurement issues in the past few years. The response rate for the construction-put-in-place survey fell in 2020, creating an increase in imputed data used to construct nonresidential construction spending. Moreover, real output growth in nonresidential construction was likely biased down in 2021 and 2022 due to measurement issues related to high cost pressures for inputs used in construction (Brandsaas et al. 2023).

result suggests that mismeasurement of labor input is not the primary reason for slow productivity growth, because otherwise growth in nominal output per hour would be lower than other industries as well.

The combination of the data shown in Figures 1 and 2 suggests that the construction-sector deflators could play a key role in explaining why construction-sector productivity growth has been so low, since productivity growth appears more normal when output is measured in nominal terms. These figures imply that the deflators for the construction industry have risen at a much faster pace than those used for output in other industries. Indeed, Figure 3 shows this to be the case. Either the price indexes used to calculate the deflators for the construction sector really have increased much faster than the prices of other goods and services over the past 30 years, or the construction-sector price indexes have been biased upward by a growing amount over time.

In this paper, we examine the potential for mismeasurement of construction-sector deflators in explaining slow productivity growth over the past 30 years. One reason to suspect a role for mismeasurement is that a proper deflator should measure the change in the price of structures holding quality constant, but the quality of structures is quite difficult to measure. To the extent that quality increases have boosted the sales prices of structures but have not been accounted for in the computation of the deflators, the deflators will be biased upward and therefore real output will be biased downward. And indeed, there are many ways in which the quality of new structures has increased over time. Structures are much more energy efficient, using better insulation and more energy-efficient heating and cooling systems. They are also more fire-resistant, for example by using grounded electrical outlets. And they use higher-quality materials, such as reinforced concrete for foundations. As we will discuss below, these types of quality improvements are not accounted for directly in the price deflators used in the construction sector.

Our research is far from the first attempt to examine slow productivity growth in the construction sector. A number of prior researchers have found evidence suggesting that mismeasurement of the deflators used to convert nominal output to real output are at least partly responsible. Allen (1985) finds that slow productivity growth from 1968 to 1978 can be explained by mismeasurement of the nonresidential construction deflators and a shift towards single-family construction, which he finds to be lower productivity than nonresidential construction. However, his results are not relevant for more modern data because the data sources used to construct the nonresidential deflators have changed and single-family construction has not continued to be a growing share of total construction. More recently, Sveikauskas, Rowe, Mildenberger, Price and Young (2016) and Sveikauskas, Rowe, Mildenberger (2018) address the measurement issue that the deflators used for some subsectors are not well-matched to the type of construction in that subsector. They show that productivity growth from 1987 to 2016 is stronger for some specific subsectors of construction for which they can match output and deflators more closely, suggesting that slow growth in other sectors might be due to measurement error. However, they are only able to conduct their analysis for a subset of sectors. As far as we are aware, this paper is the first to examine the contribution of unobserved quality increases to mismeasurement of the construction price deflators.

Other research has addressed the issue of low productivity growth by attempting to measure productivity in other ways. For example, Goodrum, Haas and Glover (2002) analyze data on the labor hours needed to complete 200 different construction-sector work activities in 1976 and 1998 and find that productivity increased materially for most activities, with an average increase of 31 percent. This result suggests that the official productivity statistics could be substantially mismeasured. By contrast, Goolsbee and Syverson (2023) show that the aggregate square footage of new single-family homes per employee in the single-family sector has been essentially flat since the 1970s, consistent with no productivity growth in this sector. Using state-level data on value added per construction worker, Sveikauskas, Rowe, Mildenberger, Price and Young (2016) find that increases in zoning regulation are associated with lower productivity growth, providing support for one reason why productivity growth may be low in this sector.

Our analysis begins with an assessment of the extent that unmeasured structure quality could have led to bias in construction-sector deflators. We take three different approaches. Our first approach studies measures of structure quality that are observable to us but not used in the Census Bureau's calculations. We obtain three such measures: an assessment of structure quality from property tax assessors, a rating of structure quality from the resident of the home, and an estimate of energy efficiency. We estimate that improvements in energy efficiency have boosted structure values by about 0.1 percentage point per year from the late 1980s to the late 2010s. The tax assessors' and residents' quality ratings have not changed much at all over time, likely because these measures are better suited for cross-sectional comparisons of quality rather than for changes over long periods of time. Using the cross-sectional correlation between quality and house value and the generous assumption that all homes built in the 1980s were low quality and all homes built in the 2010s were high quality, we estimate that unmeasured quality improvements could have boosted structure prices by about 0.5 percentage point per year. Our second approach uses detailed industry construction cost data to estimate the change in construction costs for specific housing types. This method is much less susceptible to unobserved quality bias than the Census Bureau's method because we can hold many more features of a housing unit fixed, such as the type of roof and the material used for kitchen countertops. The construction costs that we generate under this approach rise by about the same amount as the deflator used for new single-family construction, suggesting that the influence of unobserved quality increases on this deflator has been negligible. Our final approach is the application of an econometric technique for assessing the magnitude of unobserved variable bias (Oster 2019). It is based on how observed structure characteristics like unit size and number of bathrooms are correlated with the change in structure values over time, as well as on an assumption about how unobserved structure characteristics might be correlated with changes in structure value. This technique suggests that unobserved quality improvements have biased the growth rate of the single-family deflator upward by no more than 0.8 percentage point per year from 1987 to 2019.

In sum, our three different approaches suggest that unobserved structure quality has biased up the single-family deflator by an amount ranging from zero to 0.8 percentage point per year. After accounting for the fraction of nominal construction output that is deflated by this price index and making assumptions about the effect of unobserved quality on deflators used for other sectors of construction, we calculate that the resulting bias to productivity growth in the aggregate construction sector is no more than 0.5 percentage point per year.

Next we turn to three other potential sources of deflator mismeasurement. One issue is that some nonresidential sectors use a single-family price index as a component of their deflator, which would create bias if productivity growth were actually higher in these sectors than in the single-family sector. A second issue is that the single-family deflator could be biased upward because it is based on an assumption that the land share of newly-built single-family homes has been constant over time. A third issue is that nominal output in some sectors is deflated by input cost indexes rather than output cost indexes, implicitly assuming zero productivity growth. We estimate that the total bias to aggregate construction-sector productivity growth stemming from all three of these issues is quite small, around 0.2 percentage point per year. One reason why our estimates are small is that these issues pertain to only a small share of total construction-sector output. Moreover, the evidence does not support the hypothesis that productivity growth has been faster in nonresidential construction than in single-family construction, as the structure price indexes for these sectors have not risen by less than the single-family deflator. Also, we find suggestive evidence that the land share of newly-built homes may not have increased over time, even though it has clearly increased for existing structures.

Adding everything together, we find that mismeasurement error has biased construction-sector productivity growth downward by ¾ percentage point per year at the very most. This brings an estimate of average productivity growth from 1987 to 2019 up to positive territory, but just barely (from negative 0.5 percent to positive 0.2 percent), and still about 1 percentage point below productivity growth of the next-lowest major industries and more than 1½ percentage point below the average for the nonfarm business sector. Consequently, we conclude that productivity growth may well have been quite low in the construction industry, even if it has not been as low as implied by the official statistics.

The remainder of the paper proceeds as follows. Section 2 provides an overview of how productivity in the construction sector is measured. The price index used as the deflator for new single-family construction has a very large influence on aggregate construction, and so this section provides details on how this price index is calculated. Section 3 provides evidence on the potential role for measurement error in the single-family deflator related to unobserved quality improvements. Section 4 discusses other potential sources of measurement error in various construction-sector deflators. Section 5 concludes, including a discussion of potential reasons for lackluster productivity growth in the construction sector.

Section 2. Measurement of Productivity in the Construction Sector

2.1 Measurement of Nominal Output and Real Output

The BLS measures productivity in the construction sector by aggregating real output of 22 subsectors and dividing by an estimate of labor input for the entire industry.[3] The residential subsectors are new single-family construction, new multifamily construction and improvements. The nonresidential subsectors span a wide range of structures such as offices, warehouses, manufacturing structures like factories, power and communication infrastructure, and highways. The nominal shares of the 15 largest subsectors are reported in Appendix Table 1. Following the methodology used in the National Income and Product Accounts (NIPA), real output for each subsector is calculated by dividing nominal output by a deflator that is specific to that subsector. Nominal output for each subsector is based on construction spending from the Census Bureau's Value of Construction Put In Place program.[4] For new single-family

[3] Measuring productivity for each subsector separately is complicated by classification issues with labor input, as some workers in the construction industry may operate in more than one subsector.
[4] The productivity statistics use a concept of output called "sectoral output," which is defined as the total amount of goods and services produced in an industry for sale either to consumers or to businesses outside that industry.

residential construction, spending is estimated from the sales prices of newly-built single-family homes and assumptions about how the construction of a unit is spread over time from start to completion. For residential improvements, nominal spending is estimated from homeowner expenditures in the Consumer Expenditure Survey. For multifamily and nonresidential construction, nominal spending is from a survey that asks builders to estimate the nominal value of structures put in place each month.

The price deflators used to convert nominal output to real output are drawn from a variety of sources. The price deflator for new single-family construction is the price index for new single-family homes under construction produced by the Census Bureau, which we will refer to henceforth as the "single-family price index". As we will describe in more detail in section 2.2, this index estimates the constant-quality price of new single-family structures based on the sales prices and characteristics of new single-family homes. For data since 2005, the deflator for new multifamily construction is the price index for new multifamily units under construction produced by the Census Bureau, calculated using a similar method as the single-family price index. From the late 1970s to 2004, the multifamily deflator was a price index developed by the BEA for the purpose of deflating nominal construction spending (de Leeuw 1993). The deflator for residential improvements is an average of the single-family price index, the PPI for inputs to residential maintenance and repair, and the Employment Cost Index for the construction industry. Meanwhile the deflators for the nonresidential sectors differ by sector and time period. Some nonresidential sectors, such as office and health care, use a Producer Price Index (PPI) for new buildings in that specific sector. These sector-specific PPIs were developed in the 2000s and the starting dates differ a bit for each sector. For years between 1997 and the start data of each PPI, the BEA uses a sector-specific cost index that it developed from a construction cost estimator (Grimm 2003). Prior to 1997, the deflators used for all nonresidential sectors are an unweighted average of the single-family price index the Building Cost Index produced by the Turner Construction Company. For some nonresidential sectors, like lodging, there is no sector-specific PPI and an unweighted average of the single-family price index and the Turner Building Cost Index is used for the entire time period from 1987 to the present.

Table 2 lists all of the price indexes that are used as inputs to the deflators and reports the average share of nominal construction activity for which each is used over our 1987-2019 sample period. The single-family price index has the largest influence on aggregate construction, both because of the large share of new single-family construction and because this price index is used to deflate other sectors as well. In total, any bias in the single-family price index will affect nearly half of aggregate output in the construction industry. In Section 3 we will discuss how each of the other price indexes might also be affected by unobserved quality improvements. And in Section 4 we will discuss three other potential sources of bias that will be relevant to various subsets of the price indexes listed in Table 2.

Section 2.2. Methodology for the price deflator for new single-family construction

Since much of our analysis will focus on measurement issues pertaining to the price index for new single-family homes under construction, it is helpful to describe how it is computed in more detail.

The Census Bureau computes the single-family price index using sales prices and characteristics of new homes sold. The first step is a set of regressions of structure value on a set of housing unit

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Because the value of inputs is not subtracted from output, accurate output measurement does not require accurate measurement of the sector's inputs.

characteristics. These characteristics include structure square footage, number of bedrooms, number of bathrooms, presence of a basement deck, patio, or garage, type of exterior wall material, and type of heating/air conditioning.[5] Regressions are run separately for each time period and for five separate market strata: single-family attached homes and single-family detached homes in each of the four Census regions. The next step is to calculate two price indexes using the coefficient estimates from these regressions: a Laspeyres index and a Paasche index. The Laspeyres index is a weighted average of the estimated coefficients for each housing unit characteristic, with the weights based on the housing unit characteristics in 2005:

$$Laspeyres\ index_t = \frac{\sum_i p_{i,t} q_{i,2005}}{\sum_i p_{i,2005} q_{i,2005}}$$

where $q_{i,2005}$ is the average of housing characteristic *i* in 2005, $p_{i,2005}$ is the hedonic coefficient on this characteristic in 2005, and $p_{i,t}$ is the hedonic coefficient on this characteristic in time period t. The estimated regression constant is one of the hedonic coefficients in the price index. The Paasche index is similar but uses the current period housing characteristics as the fixed weights:

$$Paasche\ index_t = \frac{\sum_i p_{i,t} q_{i,t}}{\sum_i p_{i,2005} q_{i,t}}$$

Finally, the price of single-family homes under construction is the geometric mean of the Laspeyres and Paasche indexes (i.e. a Fisher Ideal index).[6]

The dependent variable in the hedonic regressions is an estimate of structure value. For homes that are built by contractors, structure value is computed as the amount paid to the contractor. However, for homes that are built for sale, structure value is not easily observable. The Census Bureau multiplies the home's sales price by a fixed factor (0.84) to subtract out the value of the project attributable to land as well as some other non-structure costs like the value of moveable appliances. [7]

Section 3. Unobserved Quality of Structures

3.1 The role of unobserved quality

To illustrate the bias imparted from omitted housing unit characteristics, consider a hedonic regression that is estimated in a repeated cross-section:

$$Y_{it} = c_t + \beta_t X_{it} + \varepsilon_{it}$$

where Y_{it} is the natural log of structure value of unit *i* in time t, X_{it} are observed housing unit characteristics, c_t is a constant estimated separately in each time period, and ε_{it} is the regression error

[5] The full list of covariates can be found at https://www.census.gov/construction/cpi/pdf/descpi_uc.pdf.
[6] The actual formulas for the price indexes are more complicated than shown here because they sum over all five market strata and because the regression coefficients are transformed to account for having been estimated in a log-linear regression.
[7] See more information here: https://www.census.gov/construction/c30/methodology.html. For contractor-built homes, the Census Bureau inflates sale amounts by a factor of 1.1 to account for other expenses related to lot development. Contractor-built houses are weighted to also represent owner-built houses.

term assumed to have a mean equal to zero. Suppose that a variable reflecting unit quality called Z also influences sales price but is unobserved to the econometrician. Then the true data-generating process is:

$$Y_{it} = c_t + \beta_t X_{it} + \gamma_t Z_{it} + \varepsilon_{it}$$

Whereas the econometrician estimates:

$$Y_{it} = c_t' + \beta_t' X_{it} + u_{it}$$

where $u_{it} = \gamma_t Z_{it} + \varepsilon_{it}$. If unobserved quality is uncorrelated with all of the components of X and if average quality is the same in each time period, then β_t' and c_t' will be unbiased estimators of β_t and c_t, respectively, and the price index computed from β_t' and c_t' is unbiased. However, if unobserved quality increases over time, then the error term u_{it} will not be mean zero, leading to a bias in c_t and therefore a bias in the price index. If quality is correlated with some of the elements of X then β_t' will be a biased estimate of β_t. However, this will not result in any additional bias in c_t' unless this correlation changes over time. In fact, a correlation between unobserved quality and the elements of X reduce the bias in c_t' if the elements of X are also increasing over time. In the limit, if unobserved quality is perfectly correlated with X, then the bias in the price index would disappear.

Therefore, the key question is whether the quality of housing structures has increased substantially in a way that is not captured by the variables included in the hedonic regressions.

3.2 Evidence on quality from R.S. Means

As motivation for how unmeasured structure quality may have changed over time, Tables 3A and 3B summarize information on unit quality from the R.S. Means Company, a construction cost estimator. The Square Foot Cost volumes published by this company describe the materials needed to build a new house of four different quality levels: economy, average, custom and luxury. Table 3A summarizes the descriptions of average-quality new homes in 1987 and 2019 and 3B summarizes descriptions of luxury-quality homes in the same two years. With the exceptions of heating source and type of exterior walls, none of the aspects of housing quality that appear in these tables are included in the hedonic regressions used to calculate the single-family price index. Therefore, they can give some insight into aspects of housing unit quality that are not accounted for in the Census methodology.

Many elements of new single-family homes have remained the same over this 32-year period. The average new home is still built with a concrete foundation and framed with 2x4 studs and ½" plywood sheathing. It has asphalt shingles on the roof, ½" drywall for the interior walls, and similar flooring. That said, some elements of homes built in 2019 are higher quality. Foundations in 2019 were made of reinforced concrete and insulated, whereas foundations in 1987 were not. The average quality new home in 2019 included a 40-gallon electric water heater, whereas the typical water heater in 1987 was only 30 gallons and gas-fired. Electric water heaters tend to be cheaper and more energy efficient than gas. The luxury-quality homes are also quite similar in 1987 and 2019. Overall, this evidence suggests that building quality has increased a bit over time, but the changes do not seem dramatic.

Comparing Table 3A with Table 3B, one can see various ways in which luxury homes are higher quality than average homes. They use thicker foundations, larger studs for framing, higher-quality roofing, and larger hot water heaters. One source of quality improvement over time could be if more newly-built homes today would fit in the luxury category rather than the economy or average category. The R.S. Means volumes do not have any information that would allow us to assess this possibility, so next we will turn to other sources of information on structure quality.

3.3 Evidence on quality from CoreLogic Residential Real Estate data

To gain a sense of the potential bias to the single-family price index from unobserved structure quality, we first turn to data on sales prices and housing characteristics from the CoreLogic Residential Real Estate (RRE) database. This property-level database covers roughly 99 percent of the US housing stock and contains property characteristics from tax assessment records and sales prices from deeds transaction records. The dataset includes many of the same housing characteristics used by the Census, such as square footage, number of bedrooms and bathrooms, and type of exterior. Importantly, the CoreLogic RRE dataset also contains a quality rating provided by tax assessors, which allows us to estimate how sales price correlates with structure quality.[8] The dataset covers the years 2000 to 2019. We restrict the sample to newly-built single-family detached homes. CoreLogic identifies newly-built homes based on information including the seller name (typically a builder for new homes) and year built.

We estimate the change in structure prices using a pooled hedonic regression:

$$Y_{it} = \gamma C_t + \beta X_{it} + \delta D_i + \varepsilon_{it}$$

where Y_{it} is the natural log of the recorded sale amount for property i in year t; $C_t$are year indicator variables; X_{it} are the observed housing unit characteristics used by the Census, and D_i are Census Division indicators. Most, but not all of the variables included in the Census specification are available in the property tax records.[9] The coefficients on the year indicators (γ) provide a measure of constant-quality price change because they show the cumulative change in the average sales price since 2000 (the omitted indicator) conditional on the housing characteristics in the model. We cluster the standard errors by county because the approach to assessing housing unit quality differs across counties.

Column 1 of Table 4 reports selected coefficient estimates from the baseline specification.[10] The coefficient on the indicator for 2019 is 0.57, illustrating that conditional on the model characteristics sales prices in 2019 were 77 percent (exp(.57)=1.77) higher in 2019 than in 2000. This cumulative increase is quite similar to the single-family price index's cumulative increase of 76 percent over the same period. Therefore we conclude that this regression provides a reasonable method for approximating the change in structure price over time, even though it uses different data and a simpler approach than the price index methodology used by the Census Bureau.[11] We have also estimated a

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[8] Adelino and Robinson (2022) also use this quality measure, although it is drawn from the ZTRAX aggregation of property tax records not CoreLogic's.

[9] Specifically, we do not have information on whether the property has a porch or a patio. We also do not know if the heating source is gas-fired.

[10] Some coefficients are not easily interpretable. For example, the specification includes unit square footage as a linear term and as ln(square footage) in keeping with the Census specification. Results are robust to using a specification that is easier to interpret.

[11] Several differences are worth mentioning. One is that we cannot observe the value of structures built by contractors since we obtain sales price from arms-length transactions. A second difference is that we do not include single-family attached homes. A third difference is that our approach assumes time invariant coefficients for each property characteristic.

Laspeyres index using the CoreLogic RRE data and find a similar cumulative increase from 2000 to 2019 (see Appendix Figure 1).

Next we examine how the regression results change when we add the tax assessor's evaluation of structure quality. The excerpt below, taken from the real estate assessment website of Fairfax County, Virginia, provides an example of the factors that affect the assessor's quality evaluations:[12]

> *The Average category covers many standard tract-built houses. These are built to at least minimum building code standards and the quality of materials and workmanship is acceptable. Good category houses are typically found in better quality tract developments or can be designed for an individual owner. The shape of the structure is generally somewhat more complex than the Average category and good quality standard materials are used throughout. The Excellent category covers properties in higher end subdivisions or standard custom houses. Excellent properties have a higher level of design and materials when compared to Good. Luxury properties are typically individually designed custom houses and exhibit very high standards of design, materials, finish, and workmanship.*

Thus, these quality ratings will capture many elements of structure quality that are not otherwise recorded in the data, such as the quality of the foundation, roof, doors, windows, or interior finishes. The categories of ratings used vary across counties; some common examples are "average" and "good." Appendix Table 2 reports the frequency of all of the ratings that appear in the CoreLogic RRE dataset. We group the responses "excellent", "luxury", "above average" and "good" into an indicator for high quality and the remaining non-missing responses into an indicator for medium/low quality. We include indicators for high-quality and missing quality in the regression, so the coefficient on the high-quality indicator reveals the price premium for high-quality structures relative to medium/low-quality structures, conditional on the variables in the Census methodology. We do not drop the cases without a quality rating because this rating is only available for 39 percent of the observations in our sample.[13]

Column 2 of Table 4 shows the coefficient estimates when the quality variable is included. The sales prices of high-quality homes are 16 log points, or about 18 percent, higher than the prices of medium/low quality homes. Comparing the first and second columns, the coefficient on the 2019 indicator variable does not changes much when the quality variable is added, indicating that the inclusion of the additional information on structure quality does not meaningfully affect the estimated total appreciation in the house value. Mechanically, the reason is because the share of high-quality homes in the sample does not change materially over the sample period. 46 percent of units with non-missing information on structure quality fall into the "high" category in 2000-2005, compared with 52 percent in 2014-2019. It could be true that quality distribution of new homes remained stable over this time period. However, another possibility is that tax assessors may gauge quality relative to other homes that they are assessing around the same time, rather than using an absolute quality standard. In this case, the quality measure would contain useful information in the cross-section but would not be

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[12] https://icare.fairfaxcounty.gov/ffxcare/content/desc.htm

[13] The missing quality ratings appears to be because many counties do not record structure quality. Quality tends to be missing for all housing units in a county or available for most housing units in a county. Results are robust to dropping observations with missing quality, limiting the sample to counties where less than 25 percent of the observations are missing quality, and including county fixed effects.

helpful in evaluating changes in quality over time. The last two columns of the table show that the estimated coefficients on the quality indicators are similar in the first 5 years of the sample and the last 5 years, illustrating that in the cross section, the correlation of the tax assessor's estimate of quality with house prices has been stable over time.

These results cannot speak directly to changes in structure quality from 1987 to 2019, both because we only have tax assessor data starting in 2000 and because the assessor's measure of quality may be relative to other homes in the same year rather than an absolute measure of quality. Nevertheless, we can use a back-of-the envelope calculation to estimate the largest possible effect that these results imply for bias in the single-family price index. Specifically, if we assume that no new homes were high-quality in 1987 and all new homes were high quality in 2019, the cumulative change in the single-family price index would be biased upward by 18 percent, which translates to an annualize growth rate of 0.5 percentage point per year.

3.4 Evidence on quality from the American Housing Survey

The analysis on quality in the CoreLogic RRE data only covers the second half of the time period that we are interested in, so we supplement this analysis with data from the American Housing Survey (AHS), which is a nationally representative survey of housing units with a primary goal of measuring the size, composition and quality of the US housing stock. Therefore, we can use these data to get an independent read on how quality affects home value spanning a longer period of time. The AHS provides three separate ways to assess structure quality: the resident's rating of unit quality, the presence of various appliances, and expenditures on utilities that will allow us to assess energy efficiency.

For this analysis, we use AHS data on newly-built single-family detached homes covering two time periods: an "early" period, which includes data on homes built between 1970 and 1989 as observed in the 1985, 1987 and 1989 National samples, and a "recent" period, which includes data on homes built between 2000 and 2019 as observed in the 2015, 2017 and 2019 National samples. Thus, the data allow us to compare structures built over two 20-year time periods three decades apart.

The first measure of quality that we examine is based on a question that asks the resident to rate the quality of their home as a place to live on a scale from 1 to 10. Since the AHS asks a separate question about neighborhood quality, we are reasonably confident that the home quality rating reflects structure quality and not local amenities. In this sample the resident's rating of housing quality is generally in the top third of the range and did not change much between the two sample periods (see Appendix Table 2). Just like the tax assessor measure, we suspect that this rating reflects an assessment of the quality of the home relative to other homes in the same time period rather than relative to homes in an earlier time period. Even so, we can use the data to estimate the cross-sectional correlation between quality and home value conditional on other housing unit characteristics.

We regress the natural logarithm of house value (as reported by the survey respondent) on a set of housing unit characteristics, indicators for Census region, an indicator for homes built in the "recent" period, and indicators for different quality ratings. Although the set of housing unit characteristics is not as complete as the set used by the Census Bureau for calculating the single-family price index, we still obtain a good approximation of the cumulative price increase from the early period to the recent period. Specifically, as shown by column 1 of Table 5, the value of homes in the recent period is 0.99 log points, or 169 percent, higher than the value of homes in the early period. The single-family price index rose by 153 percent between these two periods, a very similar amount. In column 2, we add indicators for housing unit quality. Adding these indicators does not change the coefficient estimate on the indicator for homes built in the recent period. This result is not surprising since the distribution of quality was basically the same in the two periods. The coefficients on quality show that homes with the highest quality rating are about 0.16 log points (17 percent) higher value than those with a rating of 7 or below. As shown by columns 3 and 4 of the table, this estimated effect is about the same in the two separate time periods—0.17 for homes built in the 1970s and 1980s and 0.15 for homes built in the 2000s and 2010s. Therefore, this analysis supplies supporting evidence that conditional on the housing characteristics used by the Census Bureau, high-quality new homes are about 20 percent higher value than low-quality new homes.

The second aspect of structure quality that we can observe in the AHS data is whether the home has various types of appliances: a dishwasher, a washing machine, and a clothes dryer. In principle, moveable appliances like these should not be included in structure value. In fact, part of the Census Bureau's time-invariant adjustment to sales prices is to subtract the value of appliances. However, since the adjustment is time-invariant, the price index for new single-family homes will be biased if the ratio of total value of appliances to total structure value has changed over time. Moreover, the presence of these appliances could be correlated with other aspects of structure quality. For example, homes with a dishwasher could be more likely to have higher quality kitchen countertops and cabinets. In the AHS, the fraction of new homes with dishwashers increased from 0.73 in the 1980s to 0.93 in the 2010s, while the fraction of homes with dryers rose from 0.88 to 0.96. These increases, while not very large, could signal that moveable appliances, or possibly other unobserved housing attributes that are correlated with these appliances, have become a larger fraction of home value. We assess this possibility by including indicators for each of these appliances in the regression described above. As shown in column 5 of Table 5, the coefficient estimate on the indicator for homes built in the recent period barely changes, suggesting that the contribution of such appliances to total home value has not changed over time.[14] In support of this conclusion, a survey of homebuilders found that appliances were only a small share of total structure cost and that this share did not increase from 1998 to 2019.[15] We conclude that appliances have not increased as a share of total home value from the 1980s to the 2010s, and therefore have not led to a material bias in the single-family price index.

The third aspect of housing quality that we examine in the AHS data is energy efficiency. Many improvements in housing quality over the past 40 years are intended to improve energy efficiency. Some examples include double-paned windows, better insulation, and more efficient heating and cooling systems. Although these improvements are difficult to measure individually, we can get a sense of the cumulative changes in energy efficiency of new homes by comparing the total energy use of new homes built in the 1970s and 1980s to that of new homes built in the 2000s and 2010s.

For this exercise we calculate total expenditures on utilities as the sum of annual expenditures on electricity, natural gas, heating oil, water and other fuels. We deflate these nominal expenditures by the Consumer Price Index for utilities in order to obtain an estimate of the quantity of energy used for each

[14] Including these indicators also does not affect the estimated price change when we use a Laspeyres index framework.
[15] https://www.nahb.org/-/media/8F04D7F6EAA34DBF8867D7C3385D2977.ashx

home. Then we regress the energy use for each house on indicators for unit square footage, indicators for Census region, and an indicator for homes built in the recent period. The coefficient on the indicator for homes built in the recent period shows how energy use has changed over time after conditioning on changes in the size and geographic location of housing units.[16]

As reported in Table 6, the energy use of homes built in the 2000s and 2010s was almost 25 percent lower (column 1) or $740 (column 2) per year lower than that of homes built 1970s and 1980s. While this dollar amount is not insignificant, it is only about 4 percent of the annual rental expenditures of the homes in the recent sample. To compare the energy savings with average value of the structure, we estimate cumulative savings over the life of the home by dividing the annual energy savings by a cap rate of 9.4 percent, derived from the 2019 annual report of a large single-family rental corporation.[17] Next we calculate average structure value of the homes in our sample by multiplying the average home value in the recent sample by (1-0.41), since Davis, Larsen, Oliner and Shui (2021) estimate that the share of house value attributable to land is 0.41.[18] These calculations suggest that energy savings over the life of a home are about 4 percent of average structure value. Given that this 4 percent improvement in energy efficiency occurred over a 30-year period, it suggests that this aspect of quality boosted structure value by only 0.13 percent per year.

In sum, the evidence from the AHS is similar to the evidence from the property tax records. Using the resident's assessment of unit quality, high-quality homes are about 20 percent higher value than low-quality homes after accounting for other housing unit characteristics. Therefore, a back-of-the-envelope calculation as described in the previous section would also suggest that unobserved quality could have increased by 0.5 percent per year, at most. Improvements in energy efficiency may have contributed an additional 0.13 percent per year. However, adding these two estimates might overstate the combined quality improvement if energy efficiency is included among the structure attributes that affect tax assessors' and residents' ratings of structure quality.

Section 3.5 Evidence on construction costs from R.S. Means

As another way to assess the magnitude of potential bias related to structure quality we return to the Square Foot Cost volumes produced by the R.S. Means Company, which provided detailed estimates of the cost to build various types of residential structures. Because these estimates are based on the costs of materials, labor, and overhead, unobserved structure characteristics will not influence the estimated cost to the same extent as when estimating costs using the ultimate sales price of the property. For example, a general shift from laminate kitchen countertops to granite countertops would increase the

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[16] It is important to control for unit size because new homes have become larger over time and larger homes use more energy. Ideally it would be nice to control for more detailed geographic information since weather patterns, and therefore the need to heat and cool homes, can vary materially within Census region. However, this information is not available in the public-use data.

[17] Specially, we take data from the 2019 annual report of Invitation Homes, the largest publicly traded single-family investor. In 2019 this firm owned 79,505 single-family properties with an average value of $204,304 and average monthly rental income of $1,809 (204304/(1809*12)=9.4). The comparable cap rate derived from American Homes 4 Rent—the second largest public single-family rental company—is 9.3 percent.

[18] https://www.fhfa.gov/PolicyProgramsResearch/Research/Pages/wp1901.aspx. As we will discuss below, this estimate is for all homes less than 10 years old, not only newly-built homes. The land share is probably lower for new homes since lot sizes have fallen over time. A lower land share would raise our estimated structure value and therefore lead to an even smaller estimate of the improvements in energy efficiency relative to structure value.

average sales price of new homes and bias the price index for new single-family homes under construction upward because type of countertop is not included in the Census Bureau's regression. However, it would not bias the estimate of change in structure costs using RS Means because with the Means data we can estimate the change in the cost of a home with laminate countertops. Nevertheless, the RS Means estimate is not entirely free from bias. Continuing the example of countertop quality, the RS Means estimate would be biased if the quality of laminate countertops has changed over time.

R.S. Means provides cost estimates for a variety of home types (1-story, split level, 2 story, etc.) and four quality levels of each type: economy, average, custom and luxury. We calculate the construction costs for 1-story homes and 2-story homes at each of these quality levels, yielding a total of 8 cost estimates at each point in time. As shown in Table 7, we allow unit size, number of bathrooms, type of exterior and roof, type and length of kitchen countertops, and many other unit characteristics to differ by level of quality. The costs of the characteristics also vary by quality. For example, the cost per linear foot of a laminate countertop is higher for an average quality home than for an economy quality home, presumably reflecting the use of a higher quality material. Beyond labor and materials, the cost estimates include a range of additional costs including architectural fees, site preparation costs, and contractor overhead.

Table 7 reports the estimated construction costs for each unit type in 1987 and 2019. The cost increases for all 8 housing types range from 2.7 to 3.6 percent per year, with the unweighted average equal to 3.2 percent. Meanwhile, the single-family price index rose by 3.2 percent per year over this period. If unobserved characteristics, such as changes in the type of kitchen countertop, had biased the price index upward by a material amount, then we would have expected the cost changes computed with RS Means to have increased by a smaller amount than the price index. This does not appear to be the case. While it is true that the RS Means estimates do not hold all housing characteristics fixed, the fact that holding many important characteristics fixed does not lead to a much lower estimate of cost increase suggests that the role of quality change is small.

Section 3.6 Econometric bounds on the contribution of unobserved quality

As a final way to assess the magnitude of measurement error attributable to unobserved quality, we turn to an econometric technique developed by Oster (2019). This technique is useful for placing bounds on the magnitude of coefficient bias for scenarios in which observed controls are an incomplete proxy for omitted variables. The Oster (2019) estimator uses as inputs observables (how the coefficient of interest and model R-squared change when the observed controls are included) and two assumptions about unobservables. These assumptions are: 1) the maximum R-squared if all relevant explanatory variables were observed and 2) an assumption about the influence of remaining unobservables relative to the influence of the controls we do observe. We adapt this method to our case, where the coefficient of interest is a time period indicator (i.e. the change in structure price conditional on observed characteristics).

Oster (2019) shows a consistent estimate of the coefficient of interest (β*) can be approximated using the following formula:

$$\beta^* \approx \tilde{\beta} - \delta \left[\mathring{\beta} - \tilde{\beta} \right] \frac{R_{\max} - \tilde{R}}{\tilde{R} - \mathring{R}}.$$

where $\tilde{\beta}$ and $\tilde{R}$ are the coefficient estimate and R-squared from the model with full controls, βo and Ro coefficient and R-squared from the baseline model, δ relates the importance of unobservables relative to the importance of observables, and Rmax is the maximum R-squared when all possible controls (observed and unobserved) are included.

Oster (2019) suggests rule-of-thumb bounding values of Rmax=1.3*$\tilde{R}$ and of δ=1, that is, that the influence on the coefficient of interest (the time indicator) from remaining unobervables is as important as from the observables. Oster calibrates these rule-of-thumb values by re-analyzing estimates from randomized experiments, which provide unbiased coefficient estimates by design.[19] In our case, we think δ=1 is a reasonable bounding assumption. Intuitively, this assumes improvements in various aspects of unobserved quality like interior finishes are as important to home values as our observables like square footage and number of bathrooms.

We begin with the AHS data since the data cover the full period of interest. Table 8 shows that in a regression with only region indicators, the coefficient on the indicator for homes built in the recent period is 1.19. When the full set of Census variables are included, this coefficient decreases to 0.99 and the R-squared increases by 0.18. Thus, the observed measures of quality reduce the estimated increase in home value over this 30-year period by 0.2 log point. With Rmax=1.3*$\tilde{R}$ and δ=1, the lower bound for the unbiased coefficient on the indicator for homes built in the recent period would be 0.66. Converting the coefficient estimates to annualized growth rates, we find the constant-quality price of structures would have risen at an annual rate of 2.6 percent, rather than the estimated 3.4 percent when only the Census controls are included. In other words, this calculation suggests that unobserved increases in quality have biased the rate of increase of structure prices by up to 0.8 percentage points per year.

Next we conduct the same econometric exercise using the CoreLogic RRE data described in section 3.3. The results in Table 8 show that the unobserved quality improvements may have biased the rate of increase by up to 0.2 percentage points this year. This estimate is smaller than in the AHS data because the time period coefficient falls by less when the observed measures of quality are included and because the R-squared increases by more.

Although we cannot test the appropriateness of the bounding assumptions directly, two types of evidence suggest that δ is unlikely to be larger than 1. First, we can look at the correlation of the resident's or tax assessor's assessment of structure quality with house value, since these variables are observable measures of quality that are excluded from the Census Bureau's analysis. These correlations are smaller than the correlation of unit size with house value, and either the same size as or small than the correlations of many other housing attributes with house value (see Appendix Table 4). Therefore, assuming that the correlation between unobserved characteristics with house prices is as large as the correlation between observed characteristics and house prices seems like a reasonable upper bound. Second, we note that the only way that δ could be larger than one, or even equal to one, is if the unobserved measures of quality increased by much more than the observed measures of quality. This seems unlikely to us given the large increases in observed quality: in the AHS the fraction of new single-

[19] Oster assumes results from a set of randomized experiments should be unbiased and calibrates δ=1 and Rmax=1.3*$\tilde{R}$ so that 90 percent of the results reported in these experiments still remain significant. Oster notes assuming Rmax=1 is too generous an assumption since it would imply a rejection of about 60 percent of these results.

family homes larger than 2500 square feet nearly doubled from 27 percent in the 1980s to 44 percent in the 2010s. And the fraction with at least 3 bathrooms tripled from 11 percent to 35 percent.

Section 3.7 Implications of quality bias for construction sector productivity

To summarize, we have investigated the plausible magnitude of bias due to unobserved quality using three different techniques: using measures of quality that are observable to us but not used in the Census Bureau's calculations, using estimates of construction costs from industry data that are less susceptible to unobserved quality bias, and using an econometric technique based on how the inclusion of observed quality alters the estimated change in structure prices. These estimates suggest that the price index for new single-family homes under construction is biased upward by an amount ranging from very small (when comparing with the alternate cost estimates from RS Means) to 0.8 percentage point per year (when using the Oster (2019) econometric method).

The implication for productivity growth in the aggregate construction sector depends on what portion of the construction sector is affected by the bias owing to unobserved structure quality. As we discussed in Section 2, the single-family price index is used to deflate for 46 percent of nominal spending in the construction sector. Since the price index for new multifamily units under construction is calculated using a very similar methodology, the bias in this deflator is probably similar.[20] The multifamily price index is used to deflate only 2 percent of nominal construction spending from 1987 to 2019 (Table 2), as it was not introduced until 2005. A bias of 0.8 percentage point per year in these two price indexes would translate into 0.4 percentage points per year for aggregate construction sector productivity.

It is possible that unobserved quality increase could also have led to bias in some of the other price indexes that are used as deflators for the construction sector. We suspect that unobserved structure quality is likely to have a negligible influence on the PPIs for new nonresidential buildings because they are based on changes in the costs of very specific inputs. For example, the cost of a concrete slab warehouse floor is derived from 12 specific materials such as granolithic topping, 1:1:1½ mix, 1" thick. There is very little scope for the quality of an input to change over time when defined so narrowly. For a similar reason, we suspect that the PPI for inputs to residential maintenance and repair will not be influenced by changes in the quality of construction materials. We also think that the ECI for construction workers should not be influenced by changes in structure quality since it measures only labor costs.

The influence of unobserved structure quality on the BEA's cost indexes—the nonresidential indexes used between 1997 and the introduction of the PPIs and the multifamily index used before 2005—is probably smaller than that for single-family price index because these indexes were created based on

[20] Specifically, the Census Bureau also creates this index from a sample of property sales prices and the characteristics of the buildings. Eriksen and Orlando (2022) use the RS Means cost estimator to calculate the construction cost of two multifamily building types from 2012 to 2020. They find much smaller increases in construction costs (less than 2 percent per year) than the increase in the Census Bureau's multifamily price index (5 percent per year). This result suggests that increases in building quality have biased up the multifamily price index. That said, Eriksen and Orlando's calculations assume that management and design overhead are a fixed percentage of building cost; increases in these costs might also have caused the multifamily price index to increase by more than their estimates.

the estimated cost of labor and materials for specific structure types, not based on building sales prices. However, since the inputs used for these indexes may not have been as detailed as the inputs used in the PPIs, there could be some scope for increases in input quality to boost these indexes. Therefore, we will assume that the bias related to unobserved structure quality for these indexes is half of the bias that we assume for the single-family price index. The quality bias in the other price indexes—the Handy Whitman index, the AUS telephone index, and the Turner Building Cost Index—is unclear, as we do not have much information on their methodologies. Since they are also based on input costs rather than property sales prices, we will also assume that the bias from unobserved quality in these indexes is half as large as for the single-family price index. Combined, these indexes are used to deflate 28 percent of aggregate construction spending, so we obtain an additional bias of 0.1 percentage point to aggregate construction-sector productivity growth. All told, we find that unobserved structure quality has probably reduced construction sector productivity growth by 0.5 percentage points per year over the 1987 to 2019 period, at the most.

Section 4. Other sources of bias in the construction-sector deflators

Section 4.1 Potential misuse of single-family prices in nonresidential deflators

As mentioned above, the deflators for several nonresidential construction sectors use the single-family price index as one component. Also, other nonresidential sectors used this index prior to the introduction of the BEA cost indexes in 1997. This method assumes that productivity growth in the single-family sector has been the same as in these other sectors. However, if productivity growth has been faster for nonresidential construction than for residential construction, the nonresidential deflators for these sectors would be biased upward, thereby biasing down real output and productivity growth. Allen (1985) noted this issue and calculated an alternate nonresidential deflator from 1968 to 1978 based on nonresidential construction spending. His alternate deflator did indeed increase by about 1 percentage point per year less than the new single-family price index over this period, suggesting that in the 1970s productivity growth was faster for nonresidential construction than for residential construction.

We assess the potential bias stemming from this issue in two ways. First, Figure 4 compares the single-family price index to the price indexes for nonresidential construction: the PPIs for office, industrial, warehouses, health care and new schools. Only the PPI for health care structures has a lower growth rate than the single-family price index over its entire history, and this PPI is the one available for the shortest length of time—less than 10 years. The long-run growth rates of each of the other four indexes are either the same as or higher than the growth rate of the new single-family price index. However, none of these nonresidential PPIs are available over the full 1987-2019 period of interest. The Turner Building Cost index, which is available since 1987 rose by 3.4 percent per year from 1987 to 2019, slightly faster than the 3.2 percent rate of increase of the single-family price index. Grimm (2003) also reports that nonresidential price index published by R.S. Means showed very similar appreciation from 1960 to 2002 as the nonresidential deflator in the NIPA accounts, which was the single-family price index until the late 1990s. In sum, these comparisons provide little support for the possibility that cost increases were much slower in the nonresidential sectors than the residential sector. However, since each of these indexes could be biased by unobserved structure quality to varying degrees, this comparison is fairly speculative.

Second, we consider the fairly extreme assumption that a true nonresidential price index would have risen at the average rate of all price deflators in the entire nonfarm business sector. This average rate of increase was 1.8 percent per year, 1.4 percentage points below the rate of increase of the single-family price index. If we were to use a price index with this growth rate instead of the single-family price index for each nonresidential sector that uses the new single-family price index, aggregate construction sector productivity would have been about 0.12 percentage point lower per year. This estimate is small because the substitution of the nonfarm business deflator for the single-family price index affects only about 8 percent of nominal construction output (Table 2).

Section 4.2 Bias from Rising Land Shares

Another issue related to the single-family price index is that structure value is not observed directly for most homes under construction, but rather must be inferred from house value and an assumption about the fraction of total house value attributable to structure versus land. Specifically, as we mentioned in section 2, for single-family homes built-for-sale (about 70 percent of all new single-family construction), the Census Bureau calculates structure value as the sales price multiplied by a time invariant factor that reflects the share of structure value in total house value. This time invariant adjustment assumes the fractions of house value attributable to land and structure have not changed over time. This assumption would lead to an upward bias in the single-family deflator if the share of land had, in fact, risen over time.

Prior research has found that the share of house value attributable to land has risen since the 1980s as land prices have risen more than structure prices (Case 2007; Davis and Heathcote 2007; Davis and Palumbo 2008; Davis, Larsen, Oliner and Shui 2021). However, most of this research has measured the average land share for all existing residential structures in the US. Buyers of new homes may react to higher land prices by substituting towards smaller lots (Molloy, Nathanson, and Paciorek 2022) or to areas where land prices are lower, reducing the land share for newly built homes. While most estimates of the land share are based on existing properties, one exception is Davis, Larsen, Oliner and Shui (2021) who measure the land share for homes that are less than 10 years old. For this sample of homes, land share estimates will be more strongly influenced by newly-built homes than samples based on the entire housing stock. They find that the average land share increased from 38 percent in 2012 to 41 percent in 2019. However, this increase was concentrated in a small number of counties where land prices are high and new construction is less common. If we take their estimates of land shares by county and calculate a weighted average of the change in land share using single-family construction as weights, we find that the land share did not increase from 2012 to 2019. In other words, the share of house value attributable to land did not rise in areas of the country where most of the single-family construction takes place.

Three other pieces of evidence are consistent with the notion that land shares for newly built homes may not have risen over time. First, in the CoreLogic property tax records we find that the lot sizes of homes built in 2019 were about 30 percent smaller than the lot sizes of homes built in 1986.[21] This sizable decline in lot sizes should have at least partially offset any increase in land prices. Second, we compare changes over time in the value of contractor and owner-built homes (which do not include

[21] The decline is larger, about 40 percent, when conditioning on structure size because structure size increased over this period. Moreover, the decline in lot size is more pronounced in Census tracts with a higher pre-existing population density; these tracts likely have higher land prices than less dense tracts.

land) with changes in the sale price for homes built-for-sale (which do include land) using the Census Bureau's Survey of Construction microdata files for the years 1999 (first available year) and 2019.[22] Controlling for the size of structure and division fixed effects, we find that the sales price of homes built-for-sale increased by about 60 log points over this 20-year period, only about 6 log points more than the increase in contract value of contractor and owner-built homes. Had the share of land been rising over this period, we would have expected the price of homes built for sale to have risen by much more than the increase in the value of contractor-built homes.[23] Third, a survey conducted by the NAHB found that the ratio of finished lot costs to sales price for new single-family homes was actually lower in 2019 than it was in 1998 (the first available year).[24]

We conclude that any bias in the single-family price index owing to rising land shares is likely to be small. In addition, the effect of any such bias on measurement of real construction output is mitigated by the fact that the estimate of nominal construction expenditures for new single-family homes uses the same assumption of a constant land share. Since the estimates of nominal construction spending and the price deflator both use the same assumption, any bias would cancel out. Therefore, the bias in the single-family price index would only matter for other sectors of construction that use this price index in their deflator, since these other sectors measure nominal construction spending from structure values and do not use any assumptions about land shares. As shown in Table 2, only about 18 percent of aggregate construction falls into this category. In all, we conclude that any bias to output growth in the construction sector, and therefore to productivity growth, is negligible.

Section 4.3 Input prices versus output prices

One final measurement issue to address is the fact that the deflators for some sectors are based on input prices rather than output prices. Input price indexes overstate the increase in the final cost of the structure because any productivity improvement should allow a structure to be produced at a lower cost, even if all of the input costs have not changed. The potential for bias is material, as 23 percent of nominal construction spending during our time period uses an input cost index (Table 2).[25]

To gauge the potential magnitude of this bias, we focus first on the residential improvements sector since we have better data there. The ECI for construction workers and the PPI for residential maintenance and repair are each one third of the deflator for this sector, and both measure input costs. These indexes increased by 2.9 and 2.6 percent per year, respectively, from 1987 to 2019. By contrast, the single-family price index rose by 3.2 percent per year over this period. The fact that these input cost indexes rose by less than the output price suggests that the bias from assuming zero productivity growth

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[22] The annual public SOC microfiles are available starting 1999 here https://www.census.gov/construction/chars/microdata.html

[23] Relatedly, the Census publishes a Laspeyres "houses sold" single-family price index which includes only built-for-sale homes (excludes homes built by owners and contractors). From 1987 to 2019, this index increased 167 percent compared with a 155 percent increase for the Laspeyres single-family price index including all properties. See https://www.census.gov/construction/cpi/current.html

[24] https://www.nahb.org/-/media/8F04D7F6EAA34DBF8867D7C3385D2977.ashx

[25] Prior to the 1970s almost all of construction output was deflated using input cost indexes. Methodological innovations in the 1970s and 1980s (mainly the development of the Census single-family price index) increased reliance on output price indexes. Comparing three different historical BEA methodologies, Pieper (1991) found similar rates of change for different deflator estimates in the 1963-1982 period, despite the methodological shift away from input cost indexes.

is small, since we would expect this bias to cause a faster growth rate in the input cost indexes than the output cost indexes. That said, the input cost indexes are probably not biased upward by increases in structure quality by nearly as much as the single-family price index probably is. If we subtract our higher-end estimate of quality-related bias (0.8pp per year) from the growth rate of the single-family price index, we estimate that the true cost of residential structures increased by 2.4 percent per year. This estimate is 0.5pp and 0.2pp lower than the increase in the ECI and PPI, respectively. Since they each have the same weight in deflating residential improvements, we conclude that the bias from using these two input price indexes rather than output prices could be about 0.35pp per year. These indexes combined deflate 13 percent of total nominal construction expenditures, leading to a bias in aggregate construction productivity growth of 0.05pp per year.

We cannot conduct a similar analysis for the sectors of nonresidential construction that use the Handy Whitman or AUS telephone cost indexes because we do not have access to these price indexes, nor do we have any alternative measures of output prices to compare them to. If we assume that the bias for these sectors is similar to the bias that we calculated for residential improvements, then we would find an additional bias of 0.03pp per year.

Section 5. Discussion and conclusions

Table 9 reports the contributions to bias in construction sector productivity from each of the issues that we have discussed in this paper. Cumulatively they add up to less than ¾ percentage point, even though the calculations are based on fairly generous assumptions. The construction sector's nominal share of aggregate output averaged 11 percent over our sample period, so a bias of ¾ percentage point translates into a bias in aggregate productivity growth of less than 0.1 percentage point.

Adding the cumulative bias to reported productivity growth, we estimate that productivity was essentially flat in the construction sector from 1987 to 2019. While this estimated growth rate is higher than the growth rate of the published data, it does not change the qualitative result that productivity growth in this sector has been quite low. And our estimate of productivity growth in the construction sector remains much lower than in other industries. There is still a 1 percentage point gap between the construction sector and the transportation and services sectors, the two next-lowest major industry categories. And a 1.8 percentage point gap between the construction sector and average productivity growth for the nonfarm business sector.

One final calculation can illustrate why measurement error in the price index for new single-family homes under construction is unlikely to explain why productivity growth has been so low. As measured, productivity growth in construction has been a bit more than 2 percentage points below the nonfarm business sector average. Since this price index is used as a deflator for only 46 percent of nominal construction spending, it would need to have risen by 4½ percentage points per year less than currently estimated to bring measured productivity growth up near the nonfarm business sector average. Since the price index increased by about 3¼ percent per year from 1987 to 2019, 4½ percentage points slower growth would imply that the true price of structures *fell* by about 1¼ percent per year in nominal terms over this period. That sounds extremely unlikely given the known increases in nominal construction-sector wages and other input costs.

In sum, our evidence suggests that mismeasurement of construction-sector deflators cannot explain why measured productivity growth has been so low. What about mismeasurement of nominal output or labor input? We do not have any particular reason to think that nominal output growth would be biased down by a large amount. And mismeasurement of labor input may have been biasing productivity growth *upward,* since one large source of measurement error in labor input is an undercount of undocumented workers.[26] This undercount may easily have become larger from the 1980s to the 2010s as the unauthorized immigrant population expanded.[27] With labor input having grown by a larger amount than measured, measured growth in labor input would be biased downward, leading to an upward bias in productivity growth. Goolsbee and Syverson (2023) also find little role for labor input in explaining low growth in construction-sector productivity.

Further evidence supporting the view that productivity growth has truly been slow can be found in the published statistics measuring the average length of time from start to completion of single-family homes.[28] This timeline increased from 6.2 months in the mid-1980s to 7.0 months in 2019, suggesting that any time-saving productivity improvements have been more than offset by delays elsewhere in the construction process.[29]

If construction-sector productivity really hasn't increased over the past three decades, what could explain why? One set of explanations encompasses factors that could have been a drag on productivity. For example, the expansion of zoning and other housing supply regulations that delay the construction process. Such regulations became more common in many parts of the US from the 1970s to the 2000s (Ganong and Shoag 2017, Glaeser and Ward 2009, Jackson 2016), possibly leading to longer construction timelines and making the construction process more complex. In fact, Sveikauskas, Rowe, Mildenberger, Price and Young (2016) find a negative correlation between state-level productivity growth and the frequency with which zoning is mentioned in state supreme court cases, although the magnitude of this correlation is small. Also, Millar, Oliner and Sichel (2016) find that time-to-plan for nonresidential construction projects has lengthened by more in metropolitan areas with more restrictive land use regulation. And Brooks and Liscow (2021) find that increases in Interstate infrastructure costs have been associated with an increase in land use litigation.

Although it is difficult to measure the many ways that regulations might affect the construction process and costs of construction, R.S. Means provides estimates of some direct costs in a section of their Building Construction Costs manuals that they call "General Requirements." This section lists the estimated cost of wide range of activities associated with builder overhead including the direct costs of building permits and costs related to worker safety like scaffolding, safety nets and personal protective equipment. They report that the direct cost of a building permit was the same in 1987 and 2019, ranging from 0.5 to 2 percent of total project cost in both years. The average cost of workers' compensation and employer's liability insurance was also roughly unchanged—10.4 percent of project cost in 1987 and 10.6 percent in 2019. The clearest evidence of a rise in costs is that the 2019 volume

[26] Labor input is defined as the total number of annual hours worked of all people in the industry. Any possible mismeasurement of labor quality would result in mismeasurement of total factor productivity, not labor productivity.

[27] The Pew Research Center estimates that the unauthorized immigrant population tripled from 1990 to 2017. https://www.pewresearch.org/fact-tank/2021/04/13/key-facts-about-the-changing-u-s-unauthorized-immigrant-population/

[28] https://www.census.gov/construction/nrc/data/time.html

[29] Using the Census Survey of Construction microdata files, we still find a lengthening of construction timelines from 1999 to 2019 after controlling for structure size and location.

reports some categories of costs, like personal protective equipment, that do not appear in the 1987 volume. However, we cannot assess the magnitude of these costs because they are reported as cost per item, not cost per project, and we do not know how many items are generally needed. Both volumes report that the total cost of overhead and profit ranges from 15 to 30 percent of project costs. It is difficult to see how direct regulatory costs could have increased substantially without causing total overhead to increase. A NAHB survey also shows that the costs of overhead and general expenses for single-family construction projects was about the same in 1998 (first available year) as in 2019. All told, it does not seem like the direct costs from increases regulation are large enough to significantly explain the gap in productivity growth between construction and other major industries. Of course, regulations can boost construction costs in other ways such as creating delays for inspections and requiring higher-cost designs.

Another potential restraint on productivity growth is that much more construction today could be taking place in areas that are already dense with existing structures. To illustrate this fact, we looked at the pre-existing population density where new homes were being built in the early 1990s and compared with the population density in tracts where new homes were built in the late 2010s. Figure 5 shows the distribution of population density for each cohort of homes. Indeed, new homes built between 2016 and 2019 were more likely constructed in tracts with a population density above 3000 persons per square mile, while new homes built between 1991 and 1994 were more likely to be built in tracts with less than 100 persons per square mile. Building in areas with higher pre-existing density is more expensive because is much more difficult to take advantage of gains to scale on small parcels of land where only one or two homes can fit compared with large developments of hundreds of new homes.

A second set of explanations encompasses reasons why there might not have been many labor-saving innovations in the construction sector in the first place. For example, modular housing and manufactured homes allow for much more output per worker because they take advantage of factory-production methods and returns to scale. Even though the technology to produce this type of housing has existed for many decades, it is still not common (Schmitz 2020). More generally, construction is still a very labor-intensive industry with low investment in intellectual property. Productivity growth in the education services industry—another sector that has a very low capital-to-labor ratio—has also been very low over the past 3½ decades. Future work should explore these and other possible explanations for why productivity growth in the construction sector has been so low.

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Table 1
Average Productivity Growth by Major Industry, 1987 to 2019

	Percent Change Annual Rate
Construction	-0.5
Transportation	1.2
Services	1.2
Agriculture	1.5
Nondurable Manufacturing	1.7
Mining	1.8
Finance, Insurance and Real Estate	2.1
Utilities	2.2
Durable Manufacturing	2.9
Trade	2.9
Information	4.8

Source. Bureau of Labor Statistics, Office of Productivity and Technology.

Table 2
Deflators Used in the Construction Sector

	Nominal Output Share 1987-2019
Price index for new single-family homes under construction	46.3
Used for the new single-family sector	31.4
Used for residential improvements	6.6
Used for nonresidential sectors	8.3
Price index for new multifamily units under construction	2.4
BEA multifamily price index	2.5
Nonresidential Producer Price Indexes	
Warehouse PPI	3.2
Office PPI	2.6
Industrial PPI	2.8
New school PPI	0.9
Health care	0.9
Home maintenance PPI (input cost index)	6.6
ECI for construction workers (input cost index)	6.6
Turner building cost index	8.3
BEA nonresidential price indexes	7.5
Handy-Whitman cost indexes (input cost index)	6.9
AUS telephone cost index (input cost index)	2.5

Source. Authors' calculations based on nominal output data from the Bureau of Economic Analysis and summaries of NIPA methodology from various years.

Table 3A
Housing Quality Descriptions from RS Means

	Average Quality 1987	Average Quality 2019
Foundations	• Concrete footing 8" deep x 18" wide • 8" cast in place concrete 4' deep • 4" concrete slab on 4" crushed stone base	• Concrete footing 8" deep x 18" wide • 8" reinforced concrete foundation wall 4' deep, dampproofed and insulated • 4" concrete slab on 4" crushed stone base and polyethylene vapor barrier
Framing	• 2x4 studs 16" O.C. • ½" plywood sheathing • 2x6 rafters 16" O.C • 2x6 ceiling joints 16" O.C • ½" wafer board subfloor on 1x2 wood sleepers 16" O.C.	• 2x4 studs 16" O.C. • ½" plywood sheathing • 2x6 rafters 16" O.C • 2x6 ceiling joists • ½" plywood subfloor on 1x2 wood sleepers 16" O.C.
Exterior walls	• Beveled wood siding, #15 felt building paper • Brick veneer on wood frame with 4" average quality brick • Stucco on wood frame with 1" stucco finish • Solid masonry 6" concrete block load bearing wall with insulation and brick/stone exterior	• Beveled wood siding, #15 felt building paper • Brick veneer on wood frame with 4" average quality brick • Stucco on wood frame with 1" stucco finish • Solid masonry 6" concrete block load bearing wall with insulation and brick/stone exterior
Roofing	• 240# asphalt shingles • #15 felt building paper • Aluminum gutters, downspouts, and flashings	• 25-year asphalt shingles • #15 felt building paper • Aluminum gutters, downspouts, drip edge and flashings
Windows	Wood double hung	Double hung
Exterior doors	3 flush solid core wood exterior doors, storms and screens	3 flush solid core wood exterior doors with storms
Interior walls	½" taped and finished drywall Primed and 1 coat paint	½" taped and finished drywall Primed and 2 coats paint
Flooring	• 40% finished hardwood • 40% carpet with underlayment • 15% vinyl tile with underlayment • 5% ceramic tile with underlayment	• 40% finished hardwood • 40% carpet with ½" underlayment • 15% vinyl tile with ½" underlayment • 5% ceramic tile with ½" underlayment
Interior doors	23 hollow core doors	Hollow core and louvered
Heating	Gas or oil-fired warm air furnace	Gas fired warm air heat
Electrical	• 200 AMP service • Romex wiring • Incandescent lighting fixtures, switches receptacles	• 100 AMP service • Romex wiring • Incandescent lighting fixtures, switches, receptacles
Kitchen cabinets	14 LF wall and base with plastic laminate countertop and sink	14 LF wall and base with plastic laminate countertop and sink
Water heater	30-gallon gas fired	40-gallon electric

Source. R.S. Means Company "Square Foot Costs", volumes 1987 and 2019.

Table 3B
Housing Quality Descriptions from RS Means

	Luxury Quality 1987	Luxury Quality 2019
Foundations	• Concrete footing 8" deep x 18" wide • 12" cast in place concrete 4' deep with vapor barrier • 4" concrete slab on 4" crushed stone base	• Concrete footing 8" deep x 18" wide • 12" reinforced concrete foundation wall 4' deep, dampproofed and insulated • 4" concrete slab on 4" crushed stone base and polyethylene vapor barrier
Framing	• 2x6 studs 16" O.C. • 5/8" plywood sheathing • 2x10 rafters 16" O.C • 2x10 ceiling joints 16" O.C • 5/8 plywood subfloor on 1x3 wood sleepers 16" O.C.	• 2x6 studs 16" O.C. • ½" plywood sheathing • 2x8 rafters 16" O.C • 2x6 or 2x8 ceiling joists • ½" plywood subfloor on 1x3 wood sleepers 16" O.C. • 2x10 floor joists with 5/8 plywood subfloor on models with more than 1 level
Exterior walls	• Brick veneer and #15 felt building paper on insulated wood frame • Wood siding on wood frame, cedar/redwood • Solid brick or brick on concrete block • Solid stone concrete block with fieldstone/limestone exterior	• Brick veneer and #15 felt building paper on insulated wood frame • Wood siding on wood frame, cedar/redwood • Solid brick or brick on concrete block • Solid stone concrete block with fieldstone/limestone exterior
Roofing	• Wood cedar shingles • #15 felt building paper • Copper flashing • Aluminum gutters and downspouts	• Wood cedar shingles • #15 felt building paper • Copper flashing • Aluminum gutters, downspouts and drip edge
Windows	3 solid core wood, storms and screens	3 flush solid core wood, storms
Exterior doors	Solid core or raised panel type with screen/storm	3 flush solid core wood doors with storms
Interior walls	5/8" drywall w/ skim coat plaster, primed and painted w/ 2 coats	5/8" drywall w/ skim coat plaster, primed and painted w/ 2 coats
Flooring	• 70% finished hardwood • 10% vinyl tile with underlayment • 20% ceramic tile with underlayment	• 70% finished hardwood • 10% vinyl tile with ½" underlayment • 20% ceramic tile with ½" underlayment
Interior doors	33 wood panel	Wood panel primed and painted 2 coats
Heating	Gas fired forced hot air/air conditioning	Gas fired warm air heat/air conditioning
Electrical	• 200 AMP service • Romex wiring • Fluorescent and incandescent lighting fixtures, switches receptacles • Intercom	• 100 AMP service • Romex wiring • Incandescent lighting fixtures, switches, receptacles
Kitchen	• 25 LF wall and base with plastic laminate countertop and sink	25 LF wall and base with plastic laminate countertop and sink
Water heater	75-gallon gas-fired	75-gallon electric

Source. R.S. Means Company "Square Foot Costs", volumes 1987 and 2019.

Table 4
Effect of Structure Quality on Ln(Sales Price) in Property Tax Data

	(1)	(2)	(3)	(4)
2019 Dummy	0.565***	0.567***		
	(0.005)	(0.005)		
High Quality		0.178***	0.172***	0.169***
		(0.006)	(0.001)	(0.001)
Quality missing		0.048***	0.056***	0.031***
		(0.005)	(0.001)	(0.001)
Ln(structure sq. ft)	0.866***	0.839***	0.831***	0.815***
	(0.040)	(0.036)	(0.003)	(0.005)
Structure square footage	-0.000**	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
3 Bedrooms	-0.138***	-0.125***	-0.128***	-0.122***
	(0.004)	(0.004)	(0.001)	(0.002)
4+ Bedrooms	-0.182***	-0.164***	-0.147***	-0.204***
	(0.009)	(0.009)	(0.001)	(0.002)
Bedrooms missing	-0.085***	-0.076***	-0.027***	-0.131***
	(0.013)	(0.013)	(0.002)	(0.002)
3+ Bathooms	0.125***	0.119***	0.122***	0.129***
	(0.003)	(0.002)	(0.001)	(0.001)
Bathrooms missing	0.031***	0.029**	-0.007***	0.058***
	(0.010)	(0.011)	(0.001)	(0.001)
1 Fireplace	0.025***	0.021***	0.027***	0.025***
	(0.004)	(0.003)	(0.001)	(0.001)
2+ Fireplaces	0.005	-0.003	-0.017***	-0.041***
	(0.010)	(0.010)	(0.001)	(0.003)
1-2 Garage Ports	0.017**	0.019**	0.018***	0.003***
	(0.007)	(0.008)	(0.001)	(0.001)
3+ Garage Ports	-0.010	-0.008	-0.001	-0.032***
	(0.007)	(0.009)	(0.001)	(0.001)
Unfinished Basement	0.085***	0.094***	0.060***	0.122***
	(0.007)	(0.010)	(0.002)	(0.002)
Vinyl Exterior	-0.009	-0.012*	-0.012***	-0.038***
	(0.006)	(0.007)	(0.001)	(0.002)
Wood Exterior	-0.074***	-0.082***	-0.060***	-0.066***
	(0.011)	(0.011)	(0.001)	(0.002)
Brick Exterior	0.018***	0.017**	0.036***	0.002
	(0.006)	(0.006)	(0.001)	(0.001)
Stucco Exterior	0.032***	0.035***	0.028***	0.014***
	(0.008)	(0.008)	(0.001)	(0.001)
Exterior missing	0.045***	0.044***	0.030***	0.048***
	(0.007)	(0.008)	(0.001)	(0.001)
Years	2000-2019	2000-2019	2000-2005	2014-2019
Division FE	Y	Y	Y	Y
R-squared	0.584	0.594	0.611	0.485
Observations	3,398,815	3,398,815	1,545,304	901,664

Source. CoreLogic Residential Real Estate database. Sample includes newly-built single-family detached homes from 2000 to 2019. "High quality" are homes designated by the property tax assessor as "luxury", "excellent", "above average" or "good." Standard errors (in parentheses) are clustered by county. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5
Effect of Housing Quality on Home Value in American Housing Survey

	Full Sample (1)	Full Sample (2)	Built 1970-89 (3)	Built 2000-19 (4)	Full Sample (5)
Built 2000-19	0.989	0.956	--	--	0.938
	(0.006)	(0.006)			(0.006)
Quality rating = 8	--	0.085	0.085	0.088	0.078
		(0.010)	(0.013)	(0.016)	(0.010)
Quality rating = 9	--	0.144	0.147	0.140	0.135
		(0.010)	(0.014)	(0.016)	(0.010)
Quality rating = 10	--	0.159	0.166	0.146	0.153
		(0.009)	(0.012)	(0.015)	(0.009)
Housing characteristics	Yes	Yes	Yes	Yes	Yes
Indicators for appliances	No	No	No	No	Yes
Region FE	Yes	Yes	Yes	Yes	Yes
Number observations	38,083	35,298	20,024	15,274	35,298
Adjusted R2	0.66	0.68	0.42	0.39	0.68

Source. American Housing Survey National Samples 1985, 1987, 1989, 2015, 2017, 2019. Sample restricted to single-family detached homes built 1970-1989 and appearing in the 1985-89 samples, or built 2000-19 and appearing in the 2015-19 samples. The quality rating is on a scale from 1 to 10, but few respondents rate their home quality below 7 (see Appendix Table 3). The housing characteristics are indicators for unit square footage, number of bedrooms, number of bathrooms and presence of central air conditioning, a fireplace, a garage and a basement. Indicators for appliances are three separate indicators for the presence of a clothes washer, a dryer and a dishwasher.

Table 6
Energy Use of Newly-Built Homes

	Ln(Energy Use)	Energy Use
Built 2000-2019	-0.223	-742
	(0.004)	(14)
Unit square footage		
1000 to 1499 sf	0.223	477
	(0.012)	(38)
1500 to 1999 sf	0.332	788
	(0.012)	(37)
2000 to 2499 sf	0.419	1062
	(0.012)	(38)
2500 to 2999 sf	0.498	1344
	(0.012)	(40)
3000 to 3999 sf	0.599	1735
	(0.012)	(40)
>=4000 sf	0.685	2103
	(0.013)	(43)
Region		
Midwest	-0.150	-622
	(0.008)	(27)
South	-0.129	-520
	(0.008)	(24)
West	-0.226	-795
	(0.008)	(26)
Constant	7.877	3245
	(0.012)	(40)
Number of observations	40,722	40,722
Adj. R2	0.158	0.167

Source. American Housing Survey National Samples 1985, 1987, 1989, 2015, 2017, 2019. Sample restricted to single-family detached homes built 1970-1989 and appearing in the 1985-89 samples, or built 2000-19 and appearing in the 2015-19 samples. Energy use defined as total annual expenditures on electricity, natural gas, heating oil, water and other fuels, deflated by the Consumer Price Index for Utilities.

Table 7
Construction Cost Estimates from R.S. Means

	Cost in 1987	Cost in 2019	Percent Change (annual rate)
1-story home			
Economy wood siding (800sf, 1 bath)	51,010	157,089	3.6
Average wood siding (1200 sf, 1 bath)	77,908	220,808	3.3
Custom brick veneer (1800sf, 2½ baths)	162,899	443,288	3.2
Luxury solid brick (2400sf, 2½ baths)	267,022	622,518	2.7
2-story home			
Economy wood siding (18000sf, 2 baths)	90,653	254,738	3.3
Average wood siding (2200sf, 2 baths)	114,930	321,208	3.3
Custom brick veneer (2800sf, 3½ baths)	202,876	548,146	3.2
Luxury solid brick (3600sf, 3½ baths)	327,282	790,914	2.8

Note. Economy and average homes are assumed to have an asphalt roof, a 1-car garage, an open porch and breezeway, and laminate kitchen countertops. Custom and luxury homes have a cedar shake roof, a 2-car garage, an enclosed porch and breezeway, and marble kitchen countertops. All 1-story homes have a 30-gallon gas water heater. For 2-story homes, the economy and average homes have a 30-gallon gas water heater while the custom and luxury homes have a 50-gallon gas water heater. Economy homes have 2 kitchen cabinets and 6 linear feet of countertops. Average, custom and luxury homes have 3, 4 and 5 cabinets and 14, 20 and 25 linear feet of countertops, respectively. The custom and luxury homes have a burglar alarm. All homes have air conditioning as well as a broom closet, smoke detector, dishwasher, garbage disposal, refrigerator, range, oven, microwave, washing machine, and dryer.

Table 8
Estimated Bias from Unobserved Quality Following Oster (2019)

	Coefficient on Time Period Indicator	R^2	Implied Structure Price Growth Rate (annual rate)
Regression estimates in AHS data			
Baseline	1.191	0.48	4.05
Census controls	0.989	0.66	3.35
Implied unbiased coefficient	0.767	0.86	2.59
Regression estimates in CoreLogic data			
Baseline	0.642	0.28	3.44
Census controls	0.565	0.58	3.01
Implied unbiased coefficient	0.521	0.75	2.78

Note. Baseline regression includes U.S. Census region indicator variables as controls. The 1985-89 AHS sample includes homes built from 1970 to 1989 and the 2015-19 AHS sample includes homes built from 2000 to 2019; the time period indicator is equal to one for properties built after the 2000s and zero otherwise. The CoreLogic dataset covers the period from 2000 to 2019; the time period coefficient reported is for the year 2019 (2000 is the omitted year). The implied unbiased coefficient assumes that δ=1 and that the R^2 of the regression including all unobserved variables would equal 1.3 times the R^2 of the regression with Census controls. See text for more details.

Table 9

Contributions to Bias in Aggregate Construction Sector Productivity Growth

	Percentage Points Annual Rate
Unobserved structure quality	
Reduces SF and MF price indexes by 0.8pp per year	0.39
Reduces some other nonresidential price indexes by 0.4pp per year	0.11
SF and MF price indexes include land prices	0.00
SF price index not appropriate for nonresidential sectors (1.4pp per year)	0.12
Price indexes for some sectors based on input prices	0.08
Total	0.70
Published productivity growth	-0.50
Productivity growth adjusted for total bias	0.20

Source. Author calculations described in text.

Figure 1
Productivity Growth by Major Industry

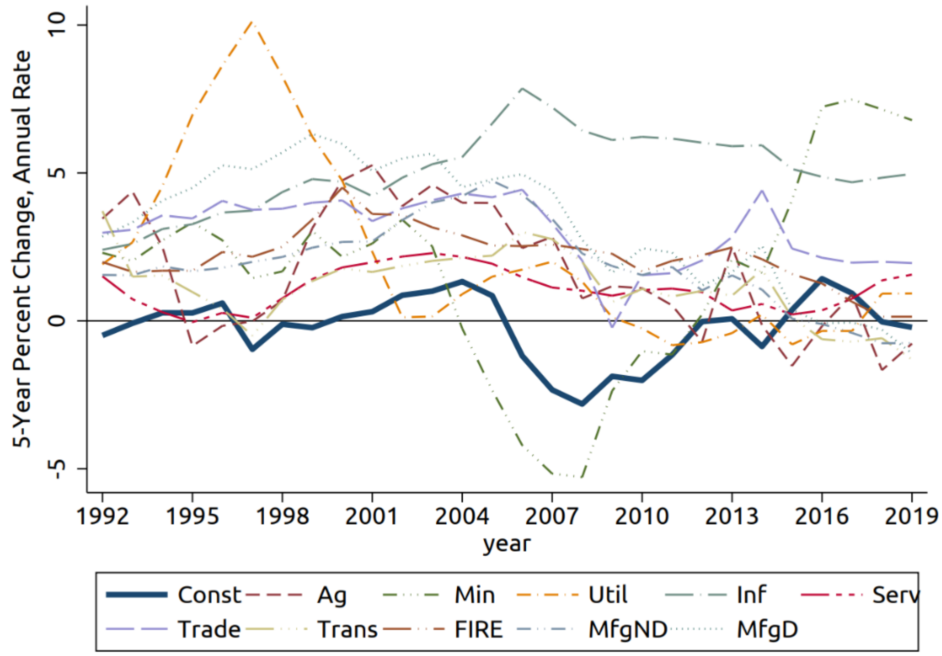
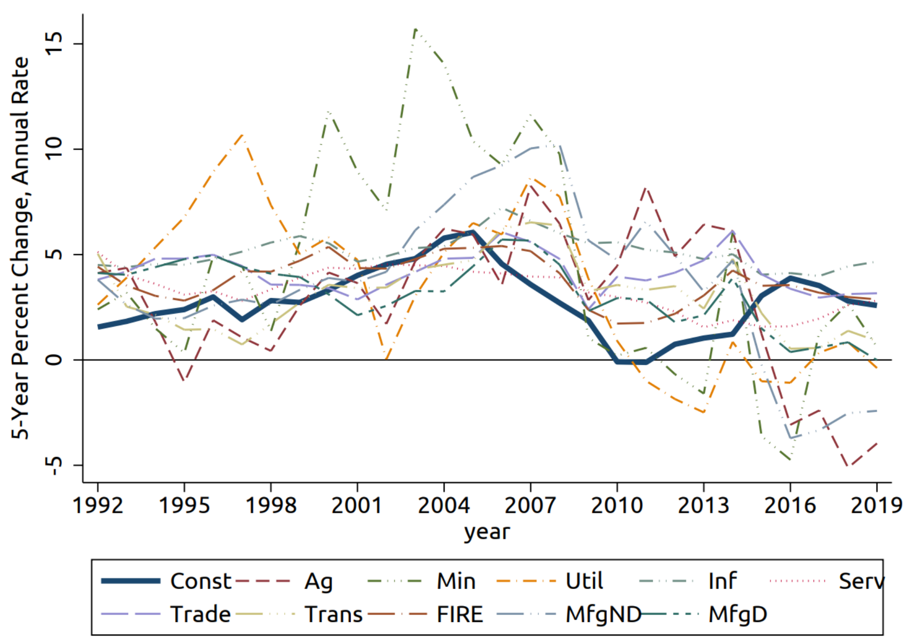
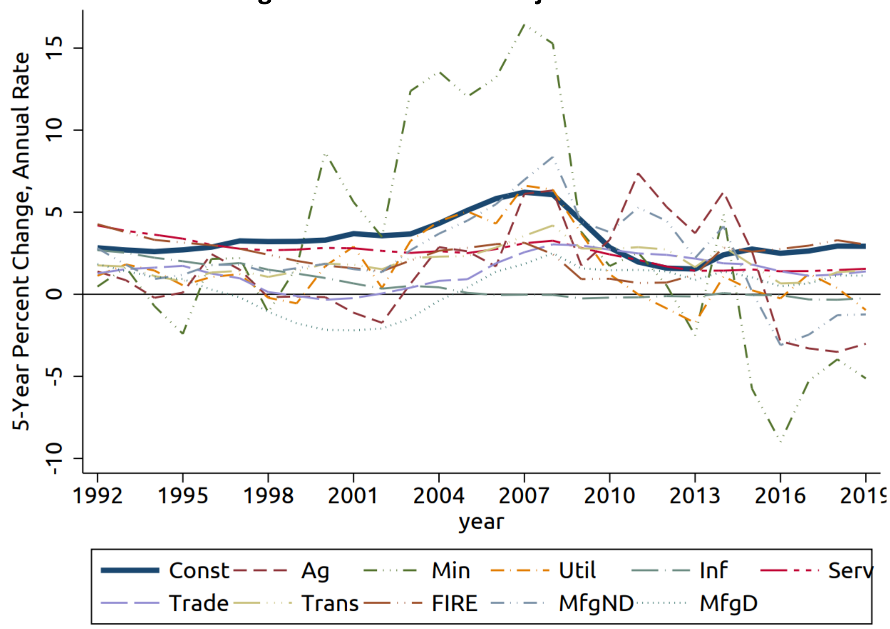


Figure 2
Growth in Nominal Output per Labor Input by Major Industry



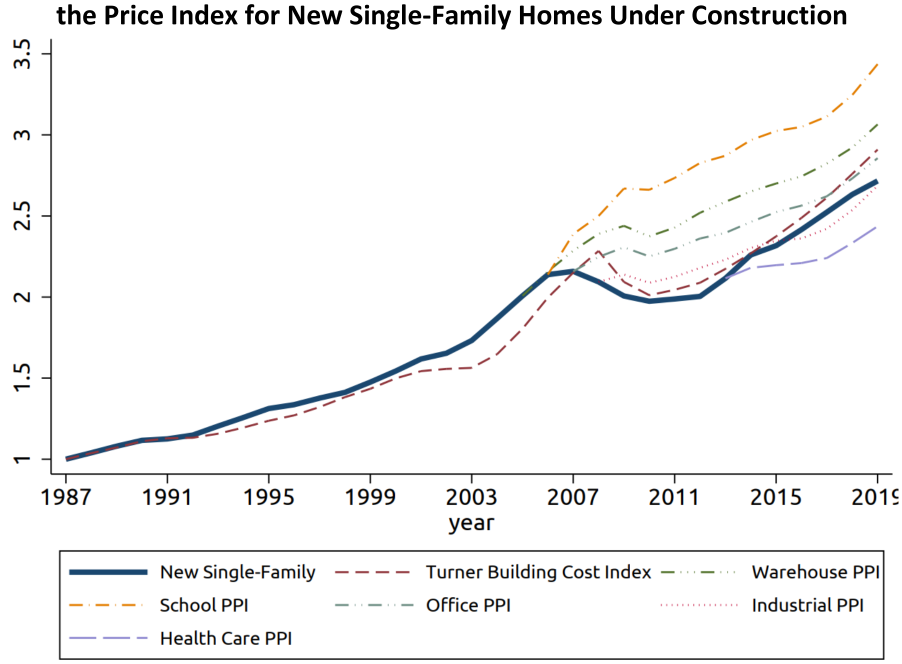
Source. Bureau of Labor Statistics, Office of Productivity and Technology.

Figure 3
Changes in Deflators for Major Industries



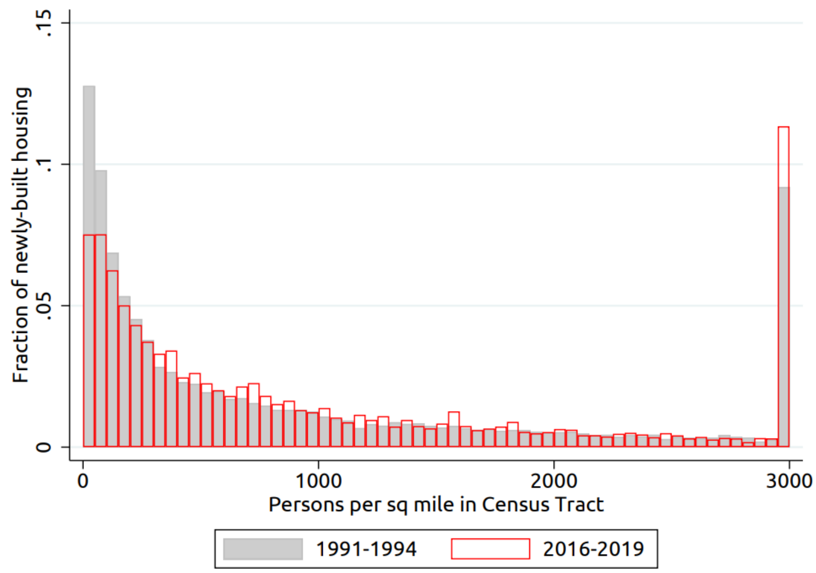
Source. Bureau of Labor Statistics, Office of Productivity and Technology.

Figure 4
Comparison of Nonresidential Structure Price Indexes with the Price Index for New Single-Family Homes Under Construction



Note. The new single-family index and Turner index are indexed to equal 1 in 1987. The PPIs are indexed to the value of the single-family index in the first year that they are available. Sources: Census Bureau, Turner Construction Company, and Bureau of Labor Statistics.

Figure 5
Density of new single-family housing



Source. IPUMS NHGIS time series tables, CoreLogic RRE, and authors' calculations. Sample of newly built housing restricted to single-family detached. Population density is measured in 1999 for 1991-1994 new housing and in 2010 for 2016-2019 new housing. Census tracts with more than 3000 persons per square mile are topcoded to 3000.

Appendix Table 1
Construction Subsector Output Shares

	Share of Nominal Construction Output 1987-2019
Residential	
New single-family	31.4
Improvements	19.7
New multifamily	4.8
Nonresidential	
Power	6.9
Office	6.7
Industrial	6.5
Health care	4.1
Lodging	2.6
Shopping malls	2.6
Telephone	2.5
Warehouse	1.8
Education	1.8
Amusement	1.6
Food establishments	1.2
Land transportation	1.0
Other	4.9

Source. Authors' calculations based on nominal output data from the Bureau of Economic Analysis.

Appendix Table 2
Property Tax Assessor's Designation of Structure Quality

Quality	Percent of Observations
Poor	0<
Below Average	0.46
Low	0.19
Economical	0.04
Average	19.08
Fair	0.67
Good	11.43
Above Average	5.25
Excellent	1.73
Luxury	0.37
Missing	60.78

Source. CoreLogic Residential Real Estate database. Sample includes newly-built single-family detached homes from 2000 to 2019

Appendix Table 3
Distribution of Resident's Rating of Home Quality

	Homes built 1970-1989	Homes built 2000-2019
Rating = 1 to 6	6.6	3.5
Rating = 7	7.6	6.9
Rating = 8	21.2	22.0
Rating = 9	16.7	18.7
Rating = 10	48.0	49.0

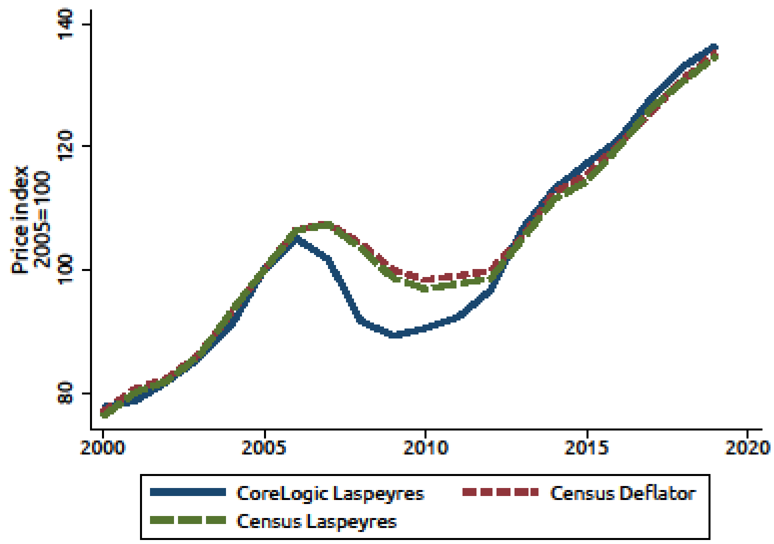
Source. American Housing Survey National Samples 1985, 1987, 1989, 2015, 2017, 2019. Sample restricted to single-family detached homes built 1970-1989 and appearing in the 1985-89 samples, or built 2000-19 and appearing in the 2015-19 samples.

Appendix Table 4
Correlation of Housing Unit Characteristics with Ln(House Value)

	AHS		CoreLogic	
	1985-89	2015-19	2001-05	2015-19
Characteristics included in Census regression:				
Unit size	0.47	0.55	0.63	0.53
Number bedrooms	0.35	0.36	0.35	0.25
Number bathrooms	0.48	0.53	0.48	0.47
Fireplace	0.39	0.29	0.06	0.04
Garage	0.29	0.19	0.00	-0.05
Porch	0.19	0.05	--	--
Basement	0.08	0.15	0.04	0.11
Central air conditioning	0.10	0.01	-0.08	-0.12
Characteristics not included in Census regression:				
Resident rating of unit quality	0.20	0.14	--	--
Tax assessor rating of unit quality	--	--	0.42	0.31

Note. For each time period ln(house value) is regressed on indicators for Census region and the table shows correlations of each variable with the regression residuals. The 1985-89 AHS sample includes homes built from 1970 to 1989 and the 2015-119 AHS sample includes homes built from 2000 to 2019. In the AHS data unit size has nine discrete values and resident rating has 5 discrete values. The tax assessor rating equals 1 for ratings of "good", "above average", "excellent" or "luxury."

Appendix Figure 1
Price Indexes for New Single-Family Structures



Source. Authors' calculations; CoreLogic RRE and U.S. Census Bureau. Indexes based on kinds of houses sold in 2005.