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ABSTRACT

Measuring productivity growth in construction is especially difficult due to the nature of production in the industry and the limitations of available data. In particular, the price indexes used to deflate output are a major problem because reliable deflators are sparse and the available data suggest productivity has declined for many decades, which is somewhat difficult to believe.

This paper first reviews Bureau of Labor Statistics (BLS) estimates of productivity growth in the overall construction sector. Second, we develop measures of labor productivity growth in three industries in construction where reliable output deflators already exist: single and multiple family residential construction from 1987 to 2011, and the construction of highways, streets, and bridges from 2002 to 2011. These data, which currently cover almost one quarter of construction output, show no sign of any sustained productivity decline. Productivity growth continues to be positive when subcontractors are included as labor input. On the other hand, the new PPIs increase more rapidly than previous unreliable output deflators did; such evidence suggests that negative long-term productivity trends are more likely than the current long-term time series data suggest.

Third, we analyze labor shifts among 31 industries in construction. Previous work (Allen, 1985) has shown that, from 1968 to 1978, shifts from high to low productivity industries reduced productivity in construction by 0.46 percent a year. Our results indicate that labor shifts still cause a considerable decline in productivity. Over the last two decades, shifts across industries reduced productivity by approximately 0.26 percent a year. However, most of the productivity decline, especially between 1997 and 2007, still remains to be explained. Fourth, we present evidence that land use regulation, measured in each state in each year, has a small but statistically significant negative effect on productivity growth in construction. The evidence also indicates that the regulation share of total costs, the amount by which regulation increases construction costs, is 3.7 percent. However, we estimate that increases in regulation reduced productivity growth in construction by only 0.1 percent a year.

Key words: Productivity growth; construction industry JEL categories: D24; L74; O47

The data in this paper are from a research project and the results do not represent official BLS productivity series. The work represents the judgment of the authors, not the views of the Bureau of Labor Statistics or the U.S. Department of Labor. We would very much appreciate any comments or suggestions which would help improve our work. Please send any proposed improvements to sveikauskas.leo@bls.gov.

Productivity Growth in Construction

Leo Sveikauskas, Samuel Rowe, James Mildenberger, Jennifer Price, and Arthur Young¹

The problem of measuring productivity growth in construction has been an important issue for many years. There are many challenges due to the nature of the industry² and the limitations of existing data. However, two issues stand out. First, there are few reliable output deflators for construction. Second, existing estimates of labor productivity or multifactor productivity growth in construction suggest that productivity has been declining for many decades, which many observers find difficult to believe.³ This paper reports some progress on these problems, which have been intractable for many years.⁴

There are four main potential reasons why productivity trends in United States construction have been negative for so long. First, United States statistical agencies may use inappropriate methods to measure productivity trends in construction. Second, productivity growth in construction may be weak or negative because of a variety of problems in the industry (Teicholz, 2004).⁵ Third, as Allen (1985) suggested in an influential article, resources may have systematically shifted towards lower productivity portions of the construction industry. Fourth, productivity growth in construction may be negative at least partially because increases in environmental regulation have held back productivity growth in this industry.

Abdel-Wahab and Vogl (2011) recently showed that the construction data contained in the Euro-KLEMS data base indicate that both labor and multifactor productivity (MFP) have declined in most countries. This evidence suggests that declining construction productivity is a real problem in many countries; the observed negative trends are consequently much less likely to reflect inappropriate

¹ The authors comprise the Productivity Growth in Construction team at the Bureau of Labor Statistics. All material in this paper represents the opinions of the authors, not the views of the Bureau of Labor Statistics.

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² It is difficult to prepare deflators for construction because the characteristics of each building and the topography of the land vary widely among projects, so that it is exceptionally challenging to compare the effectiveness of production in different contexts.

³ As Gullickson and Harper (1999, page 48) remark "If there is anecdotal evidence that phenomena [such as technological change] have been operating with a positive influence, then we might expect multifactor productivity to have a positive trend."

Important references in the literature include Stokes (1981), Allen (1985; 1989), Schriver and Bowlby (1985), and Pieper (1989). Dacy (1965) and Gordon (1968) are somewhat earlier contributions. Rojas and Aramvareekul (2003) and Abdel-Wahab and Vogl (2011) are more recent studies published in construction journals.

⁴ Pieper (1991) provides a detailed history and evaluation of methods of measuring price deflators in construction.

⁵ See also Teicholz (2013).

measurement within a single statistical system. Nevertheless, it is a real possibility that most of the deflators used to deflate construction output throughout the world are not very reliable. This paper addresses such concerns about the adequacy of output deflators by preparing accurate measures of productivity growth, based on strong deflators, for as many industries in construction as possible. In addition, we especially examine the impacts of industry shifts and of regulation.

Section I first summarizes BLS data which report negative productivity trends in U.S. construction. A major limitation of these data is that the available output deflators are questionable for many elements of construction, suggesting that measures of output and productivity derived from these deflators may not be reliable. On the other hand, measures of capital deepening or materials deepening, which do not reflect the suspect output deflators, are relatively more reliable. Therefore, Section I also considers the influence of capital and materials deepening in construction.

Because the available data on productivity growth in the aggregate construction sector does not explain the trends very well, we also search for more detailed information for particular construction industries. Section II considers long-term data on productivity growth in several industries in residential construction and in highway construction, portions of the construction sector in which adequate output price deflators are available for considerable periods of time. The latter portions of Section II examine productivity growth in these same three industries further, using plausible alternative measures of output growth and of labor input.

Section III outlines a plan to measure productivity growth in eight further industries in construction. Our plan is designed to develop accurate measures of productivity growth in as many industries as possible; in addition, these industries represent many different portions of construction. We hope that these measures of the productivity growth occurring in many industries in all parts of construction will help us understand what is happening in construction more fully. Section III also briefly compares the new PPI output price deflators with their less reliable predecessors. Section IV examines Allen's influential hypothesis that construction labor shifts from high to lower productivity industries are an important part of the productivity decline in construction. We confirm Allen's findings for more recent years, although labor shifts are somewhat less important in our data, especially since 1997. Section V develops measures of productivity growth for each of the 48 mainland states of the United States and tests whether the Ganong-Shoag (2012) measures of land use regulation, which can plausibly be expected to affect all forms of construction, can help to explain the observed negative productivity trends. The results indicate that increases in regulation do reduce productivity and productivity growth, but that regulatory restrictions explain relatively little of the observed decline in construction productivity. Section VI concludes.

I. Background

As part of its attempts to measure productivity growth in the aggregate economy, the BLS has prepared unofficial measures of MFP for a number of sectors and industries outside manufacturing. The productivity series for the construction sector are part of this data set.

Harper, Khandrika, Kinoshita, and Rosenthal (2010) (henceforth HKKR) describe BLS productivity measures for industries outside manufacturing. HKKR include a detailed description of the methods and data used in creating these measures. Their article also presents estimates of productivity growth between 1987 and 2006 in each industry. HKKR mention earlier BLS efforts to measure productivity growth in these same industries (Gullickson and Harper, 1999). This section draws upon an updated 1987-2010 version of the data described by HKKR and on the 1947-1987 data discussed in Gullickson and Harper (1999). Though the measures differ somewhat, as described in HKKR, both series present broadly consistent measures of aggregate productivity growth in construction.

Each of these data sets is prepared by standard growth accounting procedures. That is, multifactor productivity growth, \dot{A}/A , is determined from the relationship:

$$\dot{O}/O = \dot{A}/A + \alpha_K \dot{K}/K + \alpha_L \dot{L}/L + \alpha_M \dot{M}/M \quad (1)$$

where O is output, K is capital input, L labor input, and M materials input. α_K , α_L , and α_M are the respective cost shares and \dot{A}/A is the multifactor residual, the measure of productivity growth.⁶ Equation (1) is often rewritten in terms of labor productivity growth as:

$$\dot{O}/O - \dot{L}/L = \dot{A}/A + \alpha_K(\dot{K}/K - \dot{L}/L) + \alpha_M(\dot{M}/M - \dot{L}/L) \quad (2)$$

Note that, even if measures of \dot{O}/O and \dot{A}/A are unreliable because of uncertain deflators, the two latter terms of equation (2) still provide useful information on the effects of capital and materials deepening.

Table 1 summarizes the growth of each element of equation (2) for each of the periods 1958-1967, 1967-1977, 1977-1987, 1987-1997, and 1997-2010, as drawn from the unpublished BLS data described in HKKR. First, both labor productivity and multifactor productivity have been negative since 1967. Productivity growth was negative from 1967 to 1987, close to zero from 1987 to 1997, but has been substantially negative since then. Second, since 1987 labor productivity and multifactor productivity trends have been similar, so that labor productivity growth provides a reasonable approximation of multiple factor productivity growth. Third, the capital share (α_K) is consistently quite small, ranging from 0.050 to 0.103 in the annual data for the period in concern. Consequently, even rather substantial changes or measurement error in the series on capital services will have relatively little impact on the implied measures of multifactor productivity growth. Since information on capital input is very sparse in detailed industry or state data, the fact that MFP is not very sensitive to capital input is quite helpful.⁷ Fourth, the materials share (α_M) is consistently quite high, in the range of 0.456 to 0.569. With such a high materials share, materials deepening is potentially a strong influence on

⁶ Throughout this paper, materials inputs include energy and purchased business services.

⁷ The capital share is so small that fairly considerable errors in the measurement of capital input will still have relatively little impact on the implied rate of multifactor productivity growth.

labor productivity growth. However, in practice, materials grow at approximately the same rate as labor input, so that materials deepening has had relatively little impact on labor productivity growth.

Table 1. Productivity Growth in Construction: The Historical Record

Years	Labor Productivity $\dot{O}/O - \dot{L}/L$	MFP \dot{A}/A	Capital Deepening $a_K(\dot{K}/K - \dot{L}/L)$	Materials Deepening $a_M(\dot{M}/M - \dot{L}/L)$
1958-1967	2.0	0.5	0.2	1.1
1967-1977	-0.9	-1.3	0.1	0.2
1977-1987	-0.9	-0.3	-0.1	-0.4
1987-1997	-0.2	0.2	0.1	-0.5
1997-2007	-0.7	-1.2	0.3	0.1
1997-2010	-0.5	-0.9	0.4	0.1

Source: Based upon equation (2). Data are obtained from unpublished BLS listings described in Harper, Khandrika, Kinoshita, and Rosenthal (2010). Materials include energy and purchased services.

To isolate the beginning of slow productivity growth in construction somewhat more sharply, between 1958 and 1963 MFP grew at a 1.3 percent rate, but declined 0.5 percent a year between 1963 and 1967.

Information on the effect of capital deepening or materials deepening in construction is quite helpful. The Major Sector Productivity group of the BLS now provides such series on a regular basis which avoids the need to rely on external sources of data to understand the effect of capital deepening.⁸ However, the main impediment to better construction productivity numbers is still the lack of suitable output deflators. Section II below therefore turns to estimates of productivity growth based on better output price deflators.

II. Productivity Growth in Three Individual Industries in Construction.

This section prepares measures of labor productivity growth for three industries, single-family residential construction, multiple-family residential construction, and the construction of highways, streets, and bridges. These three industries are selected because they are the only industries within construction where relatively reliable output price deflators are available for a considerable period of time. The measures prepared here describe productivity growth in single-family and in multiple-family residential construction from 1987 to 2011, and also cover highway construction from 2002 to 2011.⁹

⁸ Allen (1989) and Pieper (1989) disagreed on which external measure of capital input, obtained from sources outside the BLS, provided the best indicator of capital deepening in construction. Since the BLS database on productivity growth in industries outside manufacturing now provides explicit information on capital, labor, and materials in construction, external information on capital is no longer necessary.

⁹ Residential construction (single family, multiple family, and for-sale builders) accounted for 17.7 percent of the total value of business done reported in the 2007 Census of Construction. For-sale builders are included in these calculations because, as described in the next paragraph, their production is included within single family and

To the best of our knowledge, no one has yet measured productivity growth in any of these industries using the deflators utilized in Section II.

Section IIA develops our fundamental measures of productivity growth in each of these three industries, which rely upon data from the Census of Construction. In the preparation of productivity measures, it is always crucial to make sure that the output and input data are fully consistent, so that the right amount of output is attributed to exactly the same inputs which have created that output. We rely on the Census of Construction (COC) for our primary measures because the COC is the only source which provides consistent information on output and inputs within United States construction. Section IIB considers alternative measures of construction output obtained from the Value of Construction Put in Place Survey, which the Bureau of the Census also conducts. Section IIC considers a broader concept of labor input, which includes labor inputs obtained indirectly through purchases from subcontractors as well as labor directly employed by builders.

IIA. Productivity Growth in Each of the Three Industries, As Determined from Census of Construction Data.

As discussed above, the main problem in preparing measures of productivity growth in construction is typically obtaining reliable indicators of output price. We therefore begin this section by discussing the output price deflator for each of the three industries considered.

Reliable deflators are well established for single-family and multiple family residential construction. Musgrave (1969) first created a deflator for new single family residential construction and de Leeuw (1993) developed a deflator for new multiple family residential construction. The Census Bureau and the Bureau of Economic Analysis have extended these deflators to recent years. This section uses these deflators to create an output series for two different portions of residential construction. NAICS industry 236115, new single family housing, and NAICS 236116, new multiple family housing, clearly belong in the one family and multiple family categories. NAICS 236117, new housing, for-sale builders, very largely consists of single family homes constructed by builders who own their own land. We therefore include most of NAICS 236117 with the single family category; Census data on the actual

multiple family construction. When the construction of highways, streets, and bridges is also included, the proportion of construction covered increases to 23.8 percent.

The 2007 proportions mentioned in the preceding paragraph do not occur simply because the home building sector was unusually large in 2007. In the 2002 Census the same three industries account for 24.9 percent of the value of construction work. The 2002 data reinforce the point that the three industries considered in Section II provide reliable information on productivity growth for approximately one quarter of the value of construction work.

As Table 7 below indicates, in 2007 these same three industries (again also including NAICS 236117) account for only 12 percent of labor input in construction. Residential construction accounts for a larger proportion of output than of labor because large numbers of construction contractors contribute to the output observed in residential construction; their contribution is typically treated as materials input.

products supplied by establishments classified in NAICS 236117 are used to assign for-sale construction to its different components.¹⁰

The other industry included is highway construction. The Federal Highway Administration (FHWA) has collected information on the cost of highway, bridge, and roadway construction for many years. For most of this period the FHWA published a Bid Price Index drawn from bid prices for major contract awards for federally financed highway projects. About 2000, the FHWA developed some doubts concerning the accuracy and cost effectiveness of the data underlying the Bid Price Index. A General Accountability Office (2003) report also raised further questions about the data collection procedures used in preparing the Bid Price Index.

As a result of these discussions, in 2007 the FHWA introduced the National Highway Construction Cost Index (NHCCI) to replace the Bid Price Index. The new index includes a broader more representative selection of highway projects. Though released in 2007, the NHCCI provides data as far back as 2003. The National Highway Construction Cost Index is a cost index designed to help state transportation officials understand the cost of road and bridge projects. However, the information is based on bids submitted on highway construction contracts. In addition, the NHCCI web site indicates, "This web page provides a price index that can be used both to track price changes associated with highway construction costs, and to convert current dollar expenditures on highway construction to real or constant dollar expenditures."

Because the NHCCI index is based on actual bids submitted for highway construction contracts, it is justifiable to treat this index as an output deflator. Since the NHCCI provides data from 2003, we begin analysis of productivity growth in highways in 2002.¹¹

The NAICS industry which corresponds to highway expenditures is NAICS 23731, Highway, Street, and Bridge Construction. It is important that the FHWA uses the NHCCI to deflate not only federally funded highway expenditures but also state and local highway expenditures. Specifically, a 2006 FHWA report to Congress (Federal Highway Administration, 2006, page 6-15) shows that the FHWA uses the NHCCI deflator to deflate all forms of capital outlays on highways, including state and local

¹⁰ We briefly considered developing a specific deflator for for-sale builders by combining the deflators for single family and multiple family construction in the proper proportions. The potential difficulty is that, over time, the hedonic characteristics of new houses are apt to change in different ways in the for-sale and other builder components of single family construction. We can unambiguously associate the well-known Musgrave deflator with all single family residential construction. However, if the characteristics of new structures diverge in the single family and for-sale components of single family housing, we cannot use the Musgrave indicator to deflate both components of this market separately.

To prepare separate deflators for single family housing and for for-sale builders, it would be necessary to know the characteristics of houses included in each group. The Survey of Construction contains annual Microdata Files which include the characteristics of houses. The Survey divides housing production into four categories. The "Houses Built for Sale" category is by far the largest of these four classifications. However, it does not seem possible to distinguish between single family builders and for-sale builders within these data.

¹¹ The analysis begins in 2002, rather than 2003, because 2002 is a Census year. We use the Bid Price Index to measure the price increase between 2002 and 2003.

highways as well as federal highways. Federal and state and local construction expenditures account for the great majority of expenditures in NAICS 23731. There is therefore ample precedent to use the NHCCI deflator to deflate this type of output.¹²

Now that the deflators used have been described, we briefly summarize the rest of the central data used to measure productivity growth within each of our three industries. We use data on output, on the number of employees, and on the number of partnerships and proprietorships all from the Census of Construction. The common data source is important since this ensures that these primary data items are fully consistent. However, since we need to develop annual estimates of productivity growth, it is necessary to interpolate data between Census years. We use a variety of different data series to interpolate different elements of the dataset. For example, within each industry we interpolate Census of Construction data on output using annual information on output from the Census report on Value of Construction Put in Place. Similarly, we interpolate the data on labor inputs using annual data on employment from the BLS Current Employment Statistics. Likewise, we interpolate Census of Construction data on the number of partnerships and proprietorships using corresponding data from Census files on Non-Employer Statistics.

Note that data for years between 2007 and 2012 cannot be interpolated before data from the 2012 Census become available. Until then, the 2007 data are extended linearly in proportion to their corresponding interpolating variable. This means that data for the interesting 2007 to 2012 period will all be substantially revised, and will become much more reliable, once the 2012 Census is issued. Consequently, this Working Paper will be rereleased, in a revised form, once the final version of the 2012 Census has been published.

In addition to those variables which are interpolated, values of several further data items not included in the Census of Construction are obtained from external data sources. Specifically, we obtain data on employee hours in each industry from the Current Employment Statistics. Similarly, we acquire information on the average weekly hours of partners and proprietors in construction from the BLS Current Population Survey; we have to assume that average weekly hours of partners and proprietors

¹² FHWA uses the overall CPI to deflate all maintenance and repair expenditures. Different agencies define maintenance and repair in different ways, but this category includes patching the road surface, signs, guardrails, snow and ice removal, mowing, trash pickup, and toll collection. Some of these categories, such as patching of road surfaces and guardrails, are likely to fall into the construction industry, and other elements will not. We choose to use the NHCCI deflator to deflate those elements of maintenance included in the Census of Construction, because items such as patching of road surfaces and guardrails are so closely similar to construction.

The NHCCI deflator is in some respects not as comprehensive as the well-known single and multiple family residential construction deflators. First, the NHCCI does not contain hedonic analysis, the method through which the residential deflators adjust for quality improvements over time. Second, NHCCI deflators rely on the winning bid amounts, not actual final payments, which may differ through subsequent change orders.

BLS prepared a cost based PPI for NAICS 23731, Highway, Street, and Bridge Construction between 1986 and 2010. Appendix B compares the NHCCI price deflator with the BLS cost deflator for the 2003 to 2010 period during which these series overlap. The comparison shows how drastically price based and cost deflators can differ, especially during years, like 2007 to 2009, when demand is falling rapidly. Such results illustrate the importance of obtaining reliable output price deflators for more portions of the construction industry.

are the same within each industry of the construction sector. Appendix A below describes all data sources and procedures in much greater detail.

Residential construction: Output

We consider two types of residential construction, single family and multiple family construction. Single family construction consists of NAICS 236115, single family construction, plus most of NAICS 236117, for-sale builders, which largely consists of single family construction. Multiple family construction consists of NAICS 236116, multiple family housing construction, plus a small proportion of for-sale builders.¹³

The main problem in measuring construction output has long been the absence of appropriate deflators. However, the Census Bureau has published a deflator for single family residential construction since the 1970s; this is a hedonic deflator which allows for the characteristics of new houses, such as square footage, the number of bedrooms, and the number of bathrooms.¹⁴ The Bureau of Economic Analysis similarly prepares a hedonic deflator for multiple family residential construction.

The main data on output come from the Census of Construction because it is the only source of consistent data on both output and labor input. The Census provides separate information on the value of production for employer and non-employer establishments; we combine these to prepare a single measure of overall output in each industry. For intervening years, between the Census years, information on output is obtained from the Census Bureau's Value Put in Place Survey; this survey is used to interpolate between the values of output observed in Census years.

In order to prepare a comprehensive measure of industry output, secondary business activities must be included in addition to the value of construction work.¹⁵ Table ECO72312 of the 2007 Census of Construction, Preliminary Value of Construction Work for Establishments by Type of Construction: 2007, provides detailed information on the production actually produced by all establishments classified in a given NAICS industry. We divide the production observed into four categories. The first is production primary to the industry. The second is secondary production within construction for which we have acceptable deflators, that is secondary production in single family housing, multiple family housing, or highways, streets, and bridges. The third category is secondary production in construction for which we do not currently have acceptable deflators, namely production outside our three industries. The fourth category is miscellaneous business activity, essentially the production of goods and services classified outside construction.

¹³ The discussion on page 69 in Appendix A and Table A-3 describe how the output of operative builders is divided between single and multiple family homes.

¹⁴ Appendix C provides a detailed account of how the Census Bureau prepares the single family residential construction deflator, and Appendix A lists annual values of this deflator.

¹⁵ The main products produced in an industry are called primary products. Secondary products are other products, not normally included in the industry, which establishments assigned to an industry also happen to produce.

The third category, production in other elements of construction, presents a particular problem since no good deflators are available for these industries. In 2007, 8.4 percent of the production of establishments in the single family construction industry, 19.6 percent of multiple family housing, and 13.3 percent of the production in highways, streets, and bridges consisted of secondary construction products for which no good deflator is available. Such percentages of un-priced secondary products are not unusual in Bureau of Labor Statistics measures of industry productivity, especially outside manufacturing. As is standard practice, in these instances the price of the primary product is used to approximate the price of those secondary products for which no reliable price information is available. The output of primary products and the output of each of the three types of secondary production are then all combined into a single index of overall output using Tornqvist aggregation. The result is an index of overall output for the single family homes industry and a similar index of output for the multiple family homes industry; each index covers the period from 1987 to 2011.¹⁶

Figure 1 shows output trends, for both single family and multiple family residential construction, from 1987 to 2011. The solid line, which represents single family construction, reaches a peak before the dashed line, which shows the output of multiple family homes.¹⁷ The difference between the total index of single family output and the dotted line, which shows the quality of single family houses as obtained from the hedonic measures, reflects the increased volume of single family houses.

The measures of output growth shown in Figure 1 are quite plausible. Housing output declined during the recession of the early 1990s. Output grew steadily throughout the 1990s, and expanded rapidly from 2002 to 2006 or 2007. Production declined steeply after the boom, and stabilization began in 2009 or 2010. Most of boom output consisted of an increased number of units, but single family house quality also increased modestly during the boom years.

¹⁶ Appendix A provides a more extensive discussion of how the output series is prepared.

¹⁷ Multiple family housing may lag behind single family housing because projects take longer to complete.

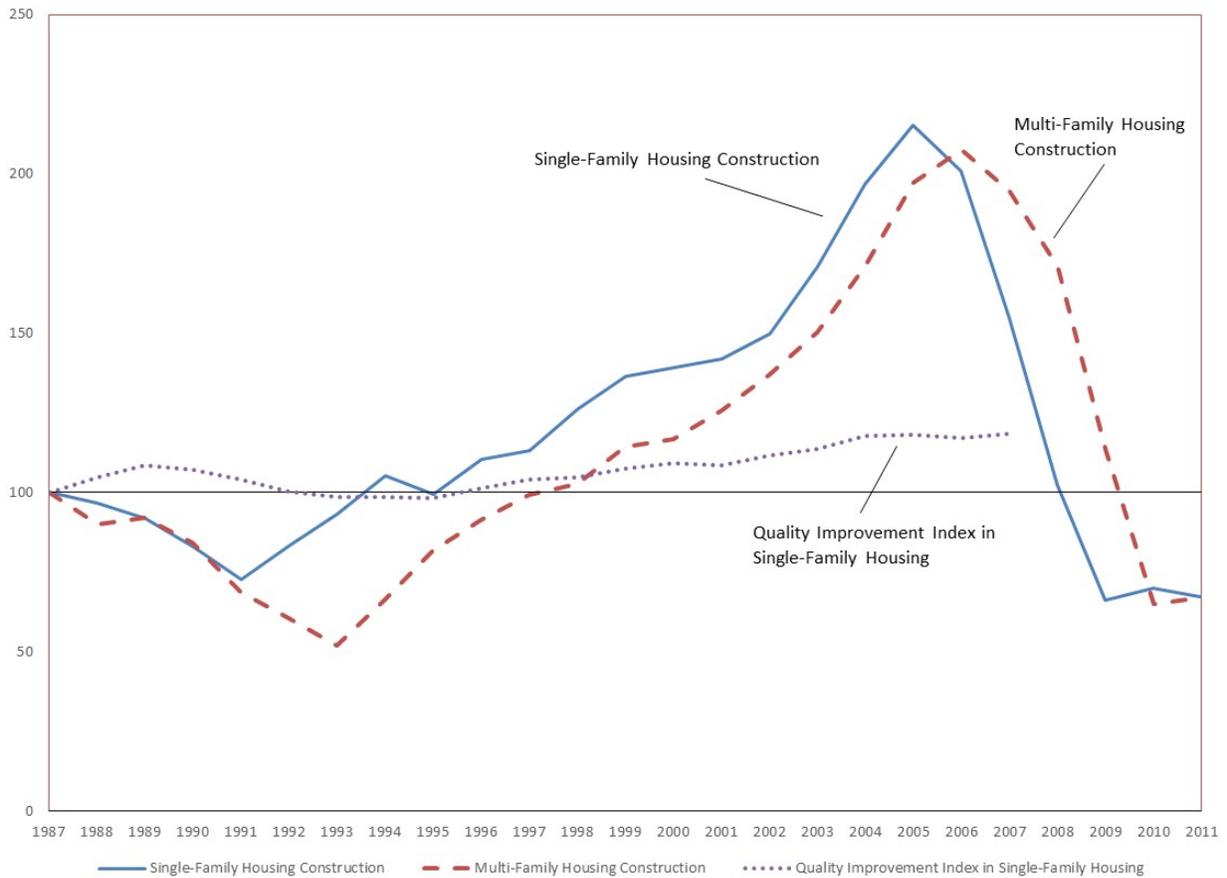


Figure 1 Output growth in Single and Multiple Family Residential Construction, 1987-2011.

Residential construction: Labor Inputs.

Labor inputs are also obtained from the Census of Construction. The Census provides data on both the number of employees and the number of partnerships and proprietorships in each industry in each Census year. Data on average weekly hours of paid employees in each construction industry are obtained from the Bureau of Labor Statistics Current Employment Statistics. Information on the hours of partners and proprietors in construction is obtained from the BLS Current Population Survey; since the CPS provides information only on construction in general, partners and proprietors are assumed to have the same average weekly hours in all industries of the construction sector. For the years between Census years, employment in each industry is interpolated on the basis of annual data from the Current Employment Statistics.¹⁸ From 1997 to 2011 the number of partners and proprietors is obtained from

¹⁸ Since output and labor are both benchmarked to the Census of Construction, data for the intervening years must be revised whenever a new Census of Construction becomes available. For example, all the estimates of productivity growth in 2008-2011 will have to be revised once the 2012 Census of Construction is released.

the Census Bureau Non-Employer Statistics program. Since the Non-Employer Statistics series begins in 1997, between 1987 and 1997 partners and proprietors are interpolated on the basis of paid employees in each industry. Finally, total labor inputs are calculated as the sum of employee hours and partner and proprietor hours.

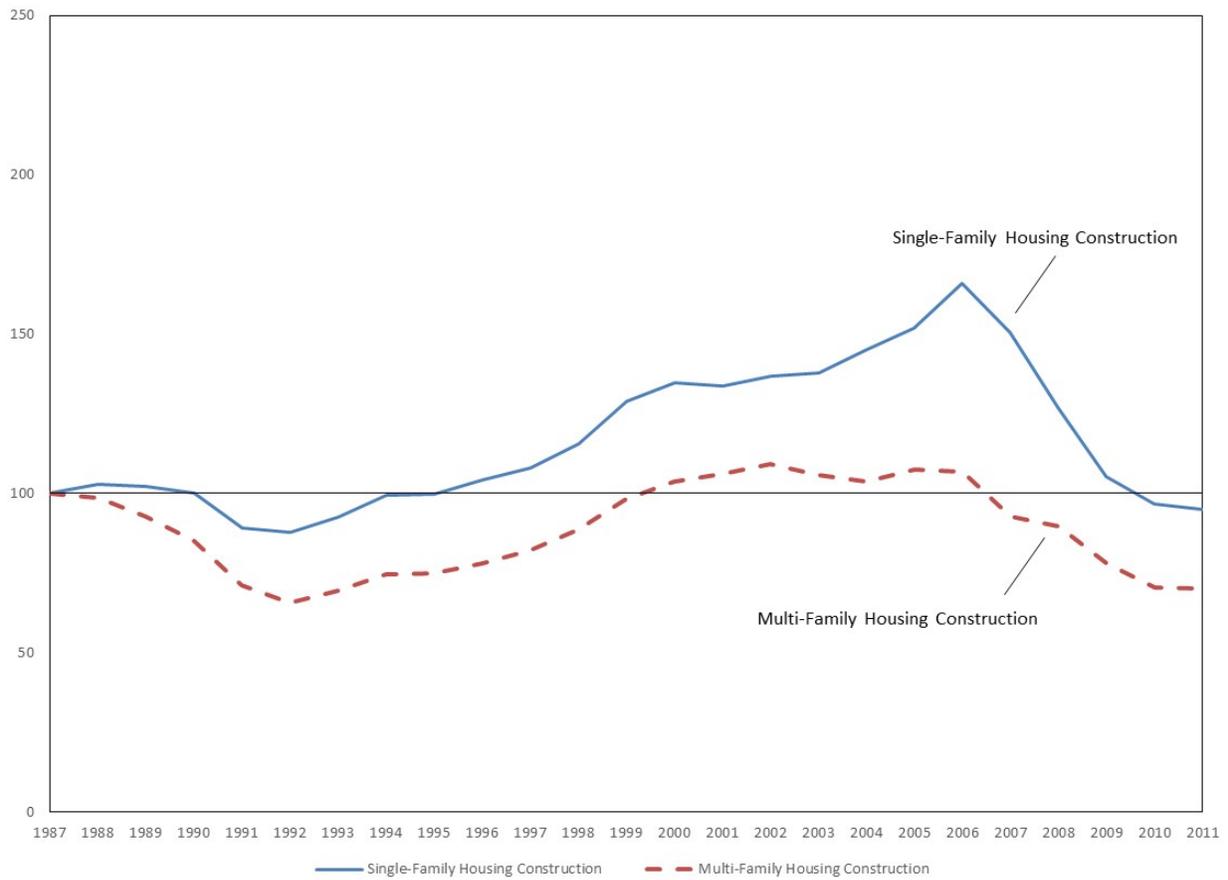


Figure 2 Total Labor Input for Single and Multiple Family Construction, 1987-2011.

Figure 2 shows total labor inputs for single and multiple family residential construction. Labor input follows similar cyclical fluctuations in the single and multiple family categories, but the labor input index is consistently greater for single family homes. During the boom period of 2000-2005, labor inputs tend to increase more slowly than the output index shown in Figure 1, suggesting that labor productivity increased substantially.

Residential construction: Labor Productivity.

Figure 3 reports labor productivity for new single-family and multiple family housing construction. Over the entire 1987 to 2011 period, labor productivity in single family housing declined at an annual rate of -1.4 percent. Over the same period, the productivity of multiple family housing declined at a rate of -0.2 percent. However, these declines reflected the sharp productivity declines

which occurred after the boom. From 1987 to 2005, productivity increased 2.0 percent annually for single family homes and 3.4 percent annually for multiple family homes. Labor productivity was relatively stagnant for both new single-family and multiple family housing construction until 1995. After 1995, however, the long term productivity rate, the trend since 1987, was consistently positive. In 2002 productivity growth rates increased sharply, peaked in 2005 to 2007, and then declined steeply.¹⁹

Two strands of evidence indicate that the long-term rate of productivity growth has been positive in residential construction. First, before the boom, from 1987 to 2000, long-term productivity growth was positive; the recession of 1991-1992 hindered housing, but once the economy had recovered, the long-term productivity trend is clearly positive. Second, as Figures 1 and 3 show, the index of output and the level of productivity follow closely similar time paths. As housing starts return to more normal levels, observed long- productivity growth is likely to revert to positive growth.²⁰

Following the output numbers, productivity in single family housing reached its peak a few years before multiple family housing did. However, the productivity index eventually fell sharply in both segments of the industry. Output trends are roughly comparable in single and multiple family homes (Figure 1), but labor inputs are consistently greater in single family building (Figure 2). Consequently, productivity growth is greater in multiple family homes (Figure 3).

¹⁹ One of our reviewers has suggested that the peak productivity observed in residential housing in 2005 to 2007 is too great of an increase to be credible. In his view, the productivity boom is exaggerated because the unprecedented demand for homebuilding labor drew in many more undocumented immigrants who do not appear in the official statistics on the work force.

There is surely merit to this view. Unfortunately, there is no reliable information on the extent to which undocumented immigrants are concentrated in homebuilding, as opposed to the rest of construction, or on how much the role of immigrants in construction changes over the business cycle. However, part of the cyclical effects established in footnote 20 below may reflect systematic errors in the measurement of labor input which are correlated with the business cycle.

²⁰ Relevant regression results support these comments. For example, in annual data for 1987 to 2011 for single family residential construction

$$\begin{array}{l} \log(O/L) = -11.13 + 0.532\log(\text{Housing Starts}) + 0.0067\text{time} \\ \text{t ratios} \quad (-4.77) \quad (23.80) \quad (5.80) \quad \bar{r}^2 = 0.963 \end{array}$$

For multiple family residential construction:

$$\begin{array}{l} \log(O/L) = -85.80 + 0.464\log(\text{Housing Starts}) + 0.0444\text{time} \\ \text{t ratios} \quad (-6.93) \quad (4.96) \quad (7.32) \quad \bar{r}^2 = 0.709 \end{array}$$

The housing start variables are specific to the type of construction being considered. The coefficients for time both indicate significant and rather substantial labor productivity growth, at a rate of 0.7 percent per year in single family housing and 4.4 percent in multiple family residential construction.

Observed productivity can increase sharply in cyclical expansions if some workers are kept on hand in slow times but work more intensively when demand is strong (Fair, 1969). In addition, greater specialization probably helps productivity when the level of output increases rapidly. Nevertheless, it is a fair point to be concerned that such influences may not be sufficient to generate the productivity peaks seen in Figure 3. The cyclical peak in productivity could be exaggerated because portions of construction cut corners in a boom, reducing quality in many small ways which are too minor to be reflected in hedonic quality measures of output, because undocumented immigrants, who work off the books, are pulled into the industry at peaks (footnote 19), or because subcontractors increasingly work in housing at peaks (Section IIC).

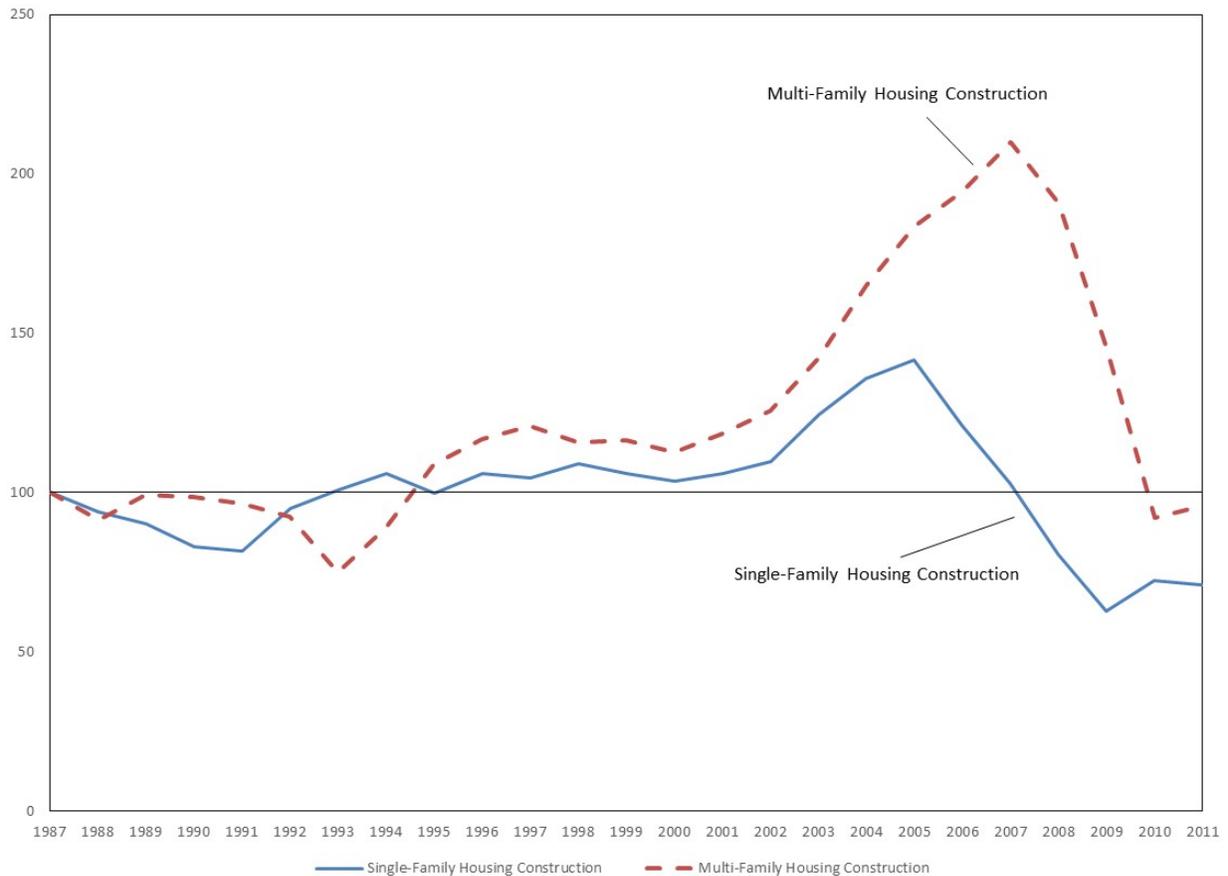


Figure 3 Labor Productivity for New Single and Multiple Family Residential Construction, 1987-2011.

Figure 4 below shows output, labor inputs, and labor productivity within NAICS 23731, the construction of highways, streets, and bridges. Overall, labor productivity in highways, streets, and bridges increased 5.9 percent per year between 2002 and 2011. For shorter time periods, observed labor productivity trends in this industry contrasted sharply with those observed in residential construction. During the housing boom of the 2000s, when residential construction experienced a substantial burst in labor productivity, output and labor productivity both declined in highway construction. After labor productivity in residential construction began to decline precipitously in 2005, labor productivity in highway construction began to rise and this industry experienced a substantial surge in labor productivity between 2008 and 2009. After 2009, labor productivity in highway construction was once again stagnant.

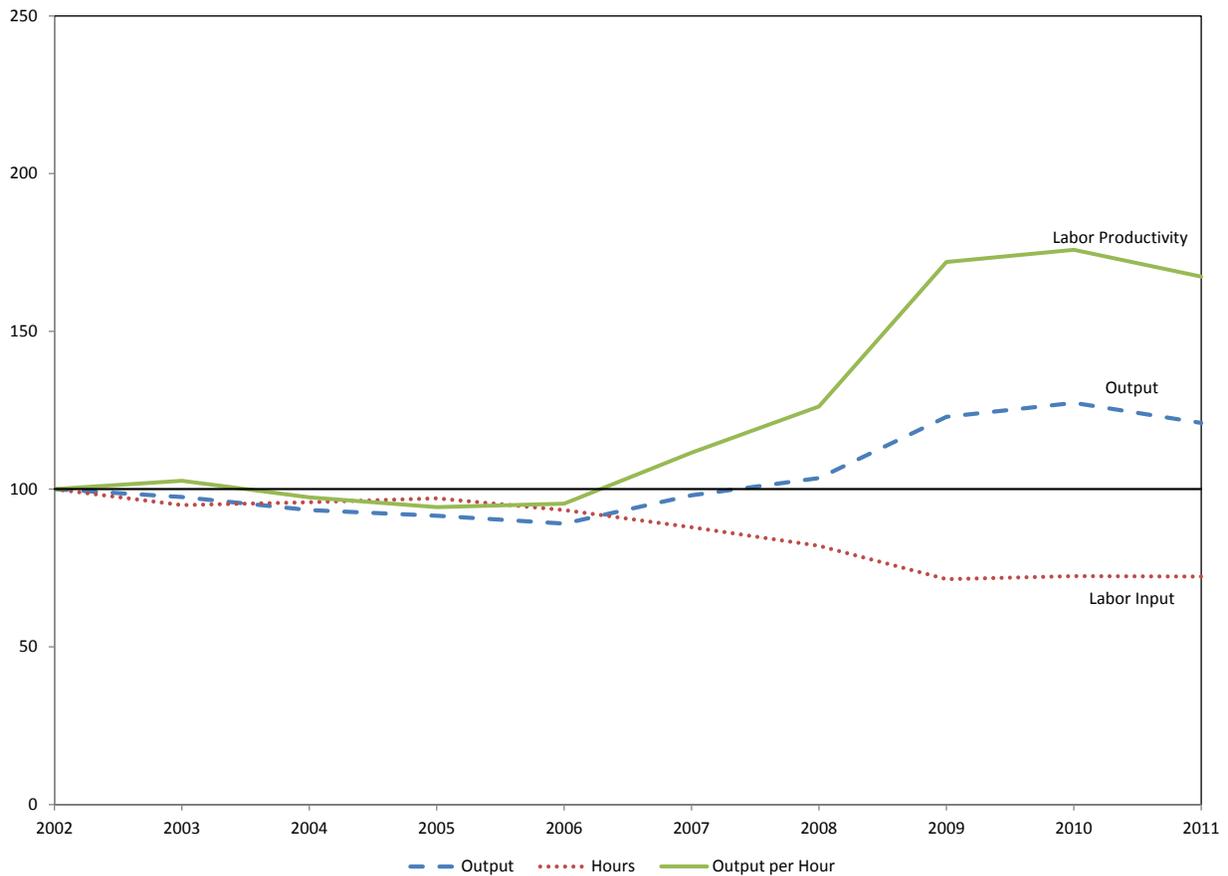


Figure 4 Output, Labor Input, and Labor Productivity in the Construction of Highways, Streets, and Bridges, 2002-2011. NAICS 23731.

Several cross currents are likely to have affected output and labor productivity growth in highways, streets, and bridges. Output and productivity growth both began to increase as early as 2006. Later, as part of the response to the steep decline in the economy, the federal government undertook a stimulus program, part of which was associated with expenditures on roads and highways. At the same time, many state and local governments fell into budget difficulties, and presumably reduced their expenditures in this area. The net effect was an increase in output which is likely to have contributed to the productivity growth observed for highways after 2008.

At the same time there may have been a compositional shift as federally financed expenditures, perhaps more capital intensive, replaced state and local expenditures. For example, the data indicate that between 2008 and 2009 the proportion of self-employed workers, presumably those most closely associated with smaller scale construction projects, declined rapidly.

At any rate, good information is now available on productivity growth in three important components of the construction industry. The evidence from these industries does not indicate that

there has been a substantial decline in productivity. It is true that productivity in residential construction declined, at -1.4 and -0.2 percent, between 1987 and 2011. However, these declines essentially reflect the collapse of the housing construction industry which occurred after 2005. From 1987 to 2005, productivity in residential construction increased steadily, at 2.0 and 3.4 percent. More meaningfully, the 1987 to 2000 or 1987 to 2002 periods, before expansion crested, show no evidence of a productivity decline in these important segments of the construction industry. In addition, the highways, roads, and bridges component of the industry shows a productivity increase from 2002 to 2011, though the trend observed in this portion of the industry at least partially is likely to reflect countercyclical expenditures.²¹

IIB. Measures of Productivity Growth Based on Alternative Measures of Output.

The discussion so far has prepared productivity measures based on output and labor input from the Census of Construction. We select the measures outlined in Section IIA as our primary measures of productivity growth because the output and labor series from the COC are fully consistent. In addition, the Census of Construction provides measures of gross output per hour which are similar in concept, and therefore comparable to, Division of Industry Productivity Studies measures of labor productivity growth in many other sectors of the economy.

However, many experts in construction tend to emphasize alternative measures of output. Most industry observers routinely prefer to measure construction output through the Census Bureau series on the Value of Construction Put into Place. Value Put in Place data are available monthly, in contrast to Census of Construction data which are available only once every five years. Not surprisingly, industry analysts typically emphasize the Value Put in Place output data. Section IIB therefore considers alternative productivity measures based on the Value Put in Place output data. Such calculations show how sensitive the productivity estimates are to a plausible alternative version of output.

Figures 5, 6, and 7 compare output growth within the Value Put in Place data with the corresponding measures of output from the Census of Construction. Figure 5 shows output of single family housing, Figure 6 deals with multiple family housing, and Figure 7 describes the output of highways, streets, and bridges. The same deflator is applied to each expenditures series, so the differences in real output fully reflect the expenditures data.

²¹ A reviewer has raised the valid point that the Census of Construction typically reports the year in which construction is completed rather than the year that construction activity occurs. The Census made this choice because they found that firms are usually not able to report the year in which construction activity actually occurs. Such lumpiness suggests that estimates of year to year productivity growth may be subject to considerable error. On the other hand, long-term measures will be much less affected by this problem; long-term measures should perhaps be prepared as three-year averages at the beginning and end of the long-term periods to avoid this potential difficulty.

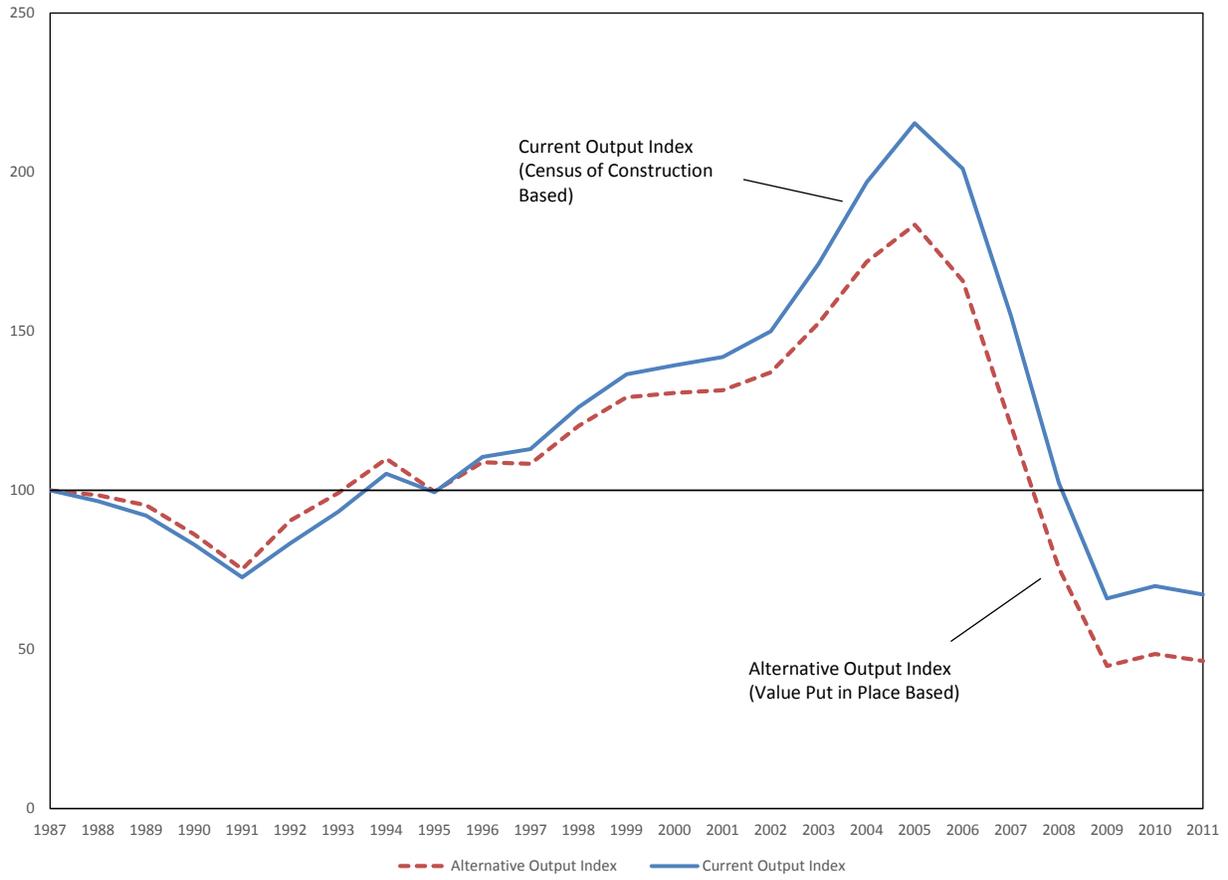


Figure 5 Real Output of Single Family Residential Construction.

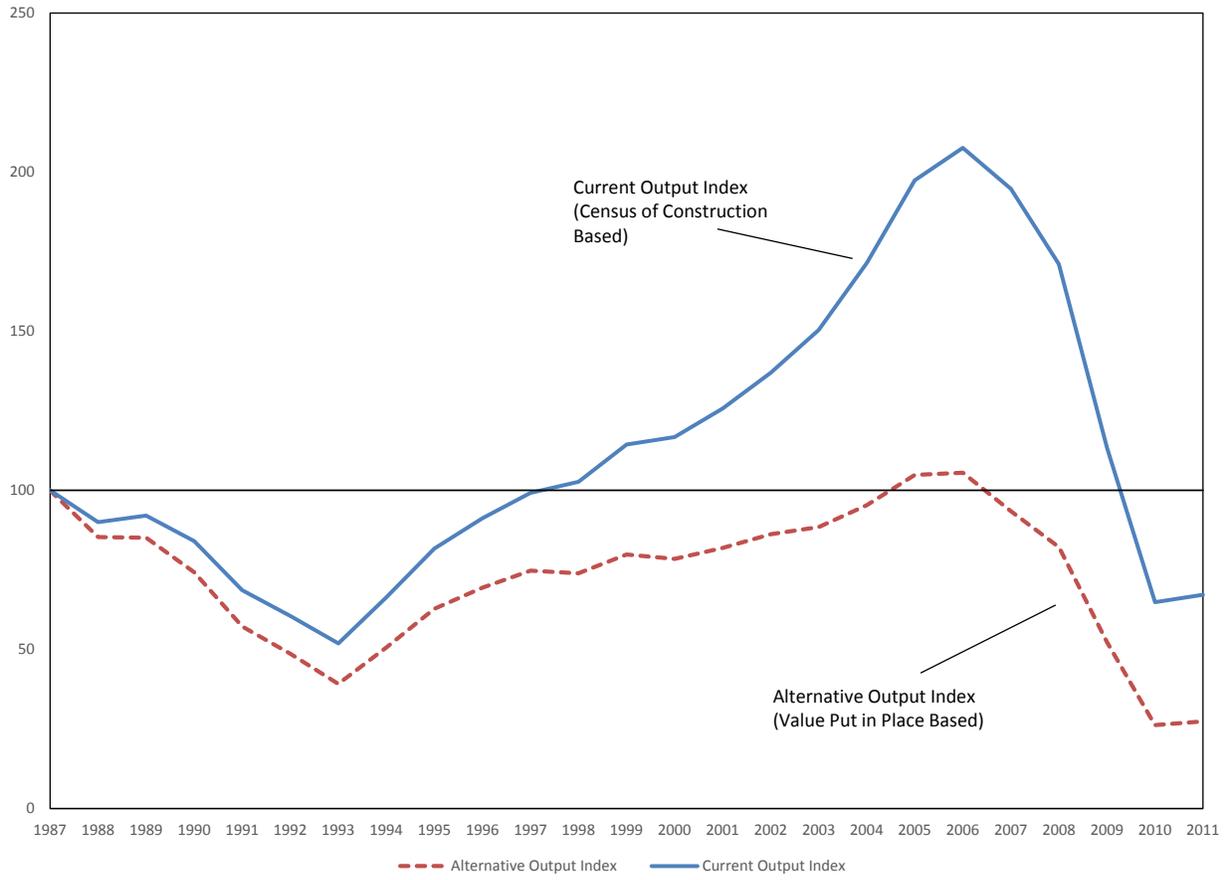


Figure 6 Real Output of Multiple Family Residential Construction.

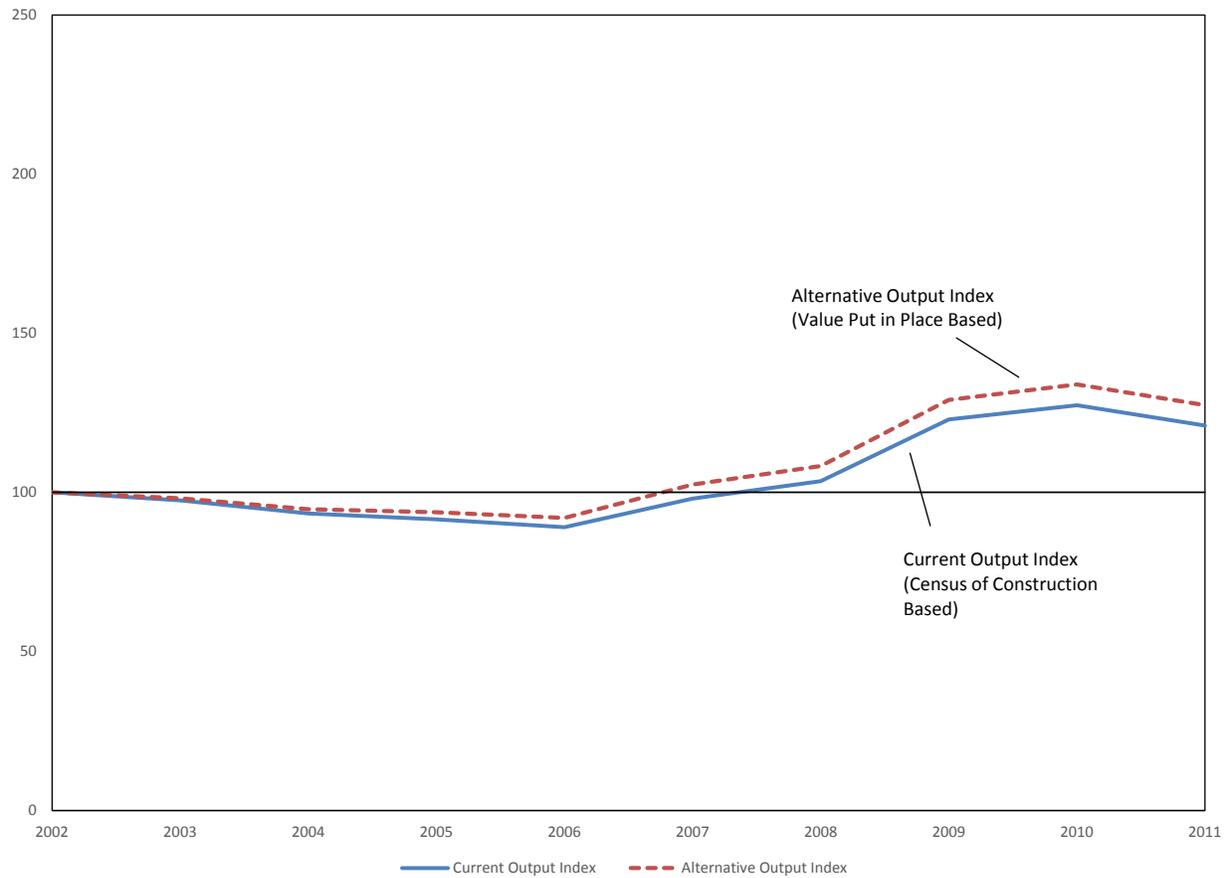


Figure 7 Real Output of Highways, Streets, and Bridges.

Figure 5 shows that the Census of Construction data indicate that single family homes reach a considerably higher peak in 2005 than the Value Put in Place data indicate. Figure 6 shows that multiple family housing reaches a much higher peak in the Census data than the Value Put in Place series suggests. Figure 7 shows that, in contrast to the residential construction series, the output index for highways, roads, and bridges is greater with the Value Put in Place output series.

Table 2 shows how these differences in output translate into labor productivity. Of course, labor inputs are the same in both scenarios, so the different productivity trends fully reflect only the two alternative series on output growth.

Table 2 Labor Productivity: Effect of Alternative Output Series on Labor Productivity Growth.

Panel A	1987-2011		1997-2007	
	Average Annual Rate of Change		Average Annual Rate of Change	
Type	Census	Value Put in Place	Census	Value Put in Place
Single Family	-1.4%	-2.9%	-0.2%	-2.2%
Multifamily	-0.2%	-3.8%	5.7%	1.0%

Panel B	2002-2011	
	Average Annual Rate of Change	
Type	Census	Value Put in Place
Highways, Streets, and Bridges	5.9%	6.5%

Not surprisingly, in view of Figure 6, productivity growth is sharply lower in multiple family housing when the Value Put in Place data are used. Single family productivity is moderately lower with the Value Put in Place series, but highways, streets, and bridges are slightly more productive with this alternative output series.

Several of our readers have commented that the high productivity levels observed during the peak expansion years of 2005 to 2007 provide important information which is relevant in considering the plausibility of any proposed productivity series. Therefore, we supplement the summary measures of long-term productivity growth provided in Table 2 with detailed graphs which illustrate the course of productivity growth over each of the individual years included in the long-term trend. Figure 8 describes productivity growth, under each of the two alternative output measures, within single family residential construction. Figure 9 provides a similar description of productivity growth in multiple family residential construction, and Figure 10 reports on highways, streets and bridges.

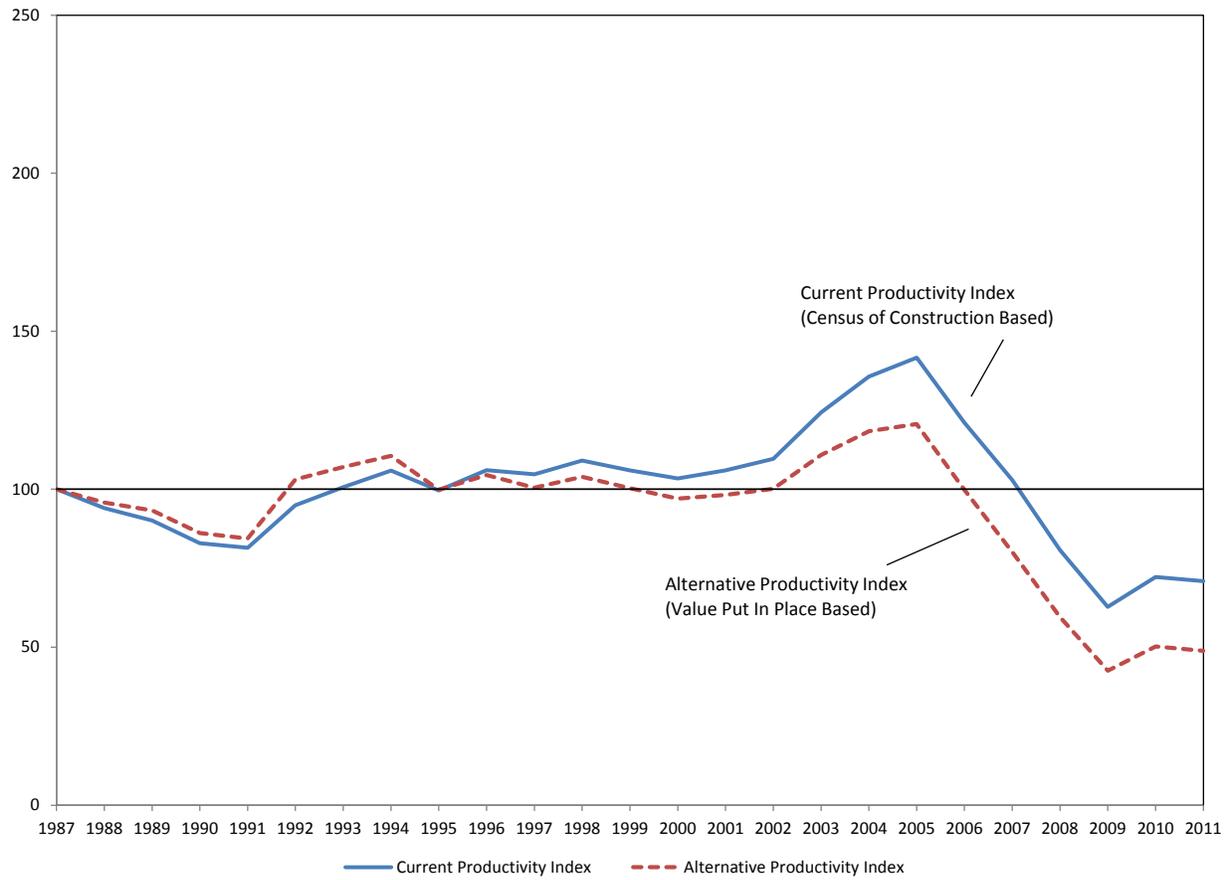


Figure 8 Labor Productivity, Single-Family Construction, Alternative Measures of Output

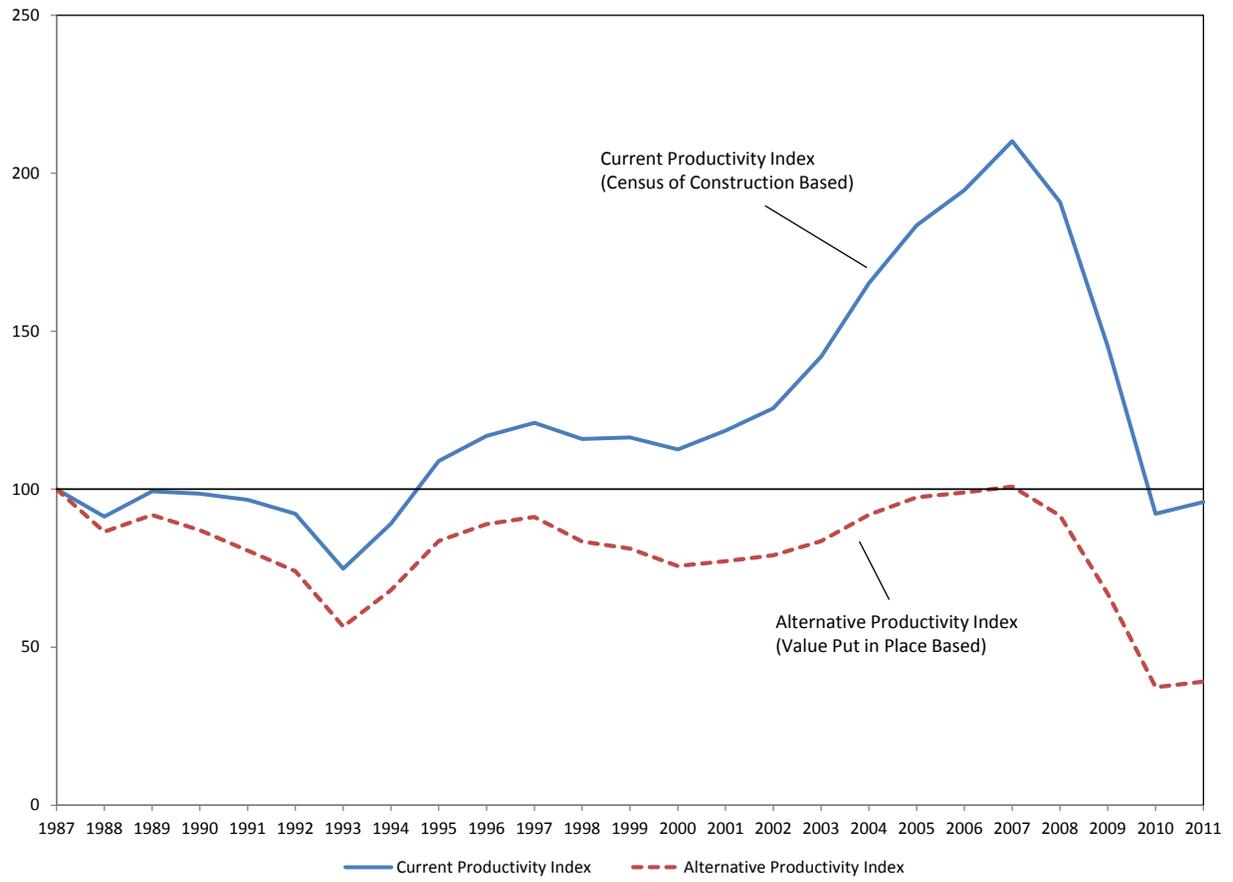


Figure 9 Labor Productivity, Multiple Family Construction, Alternative Measures of Output

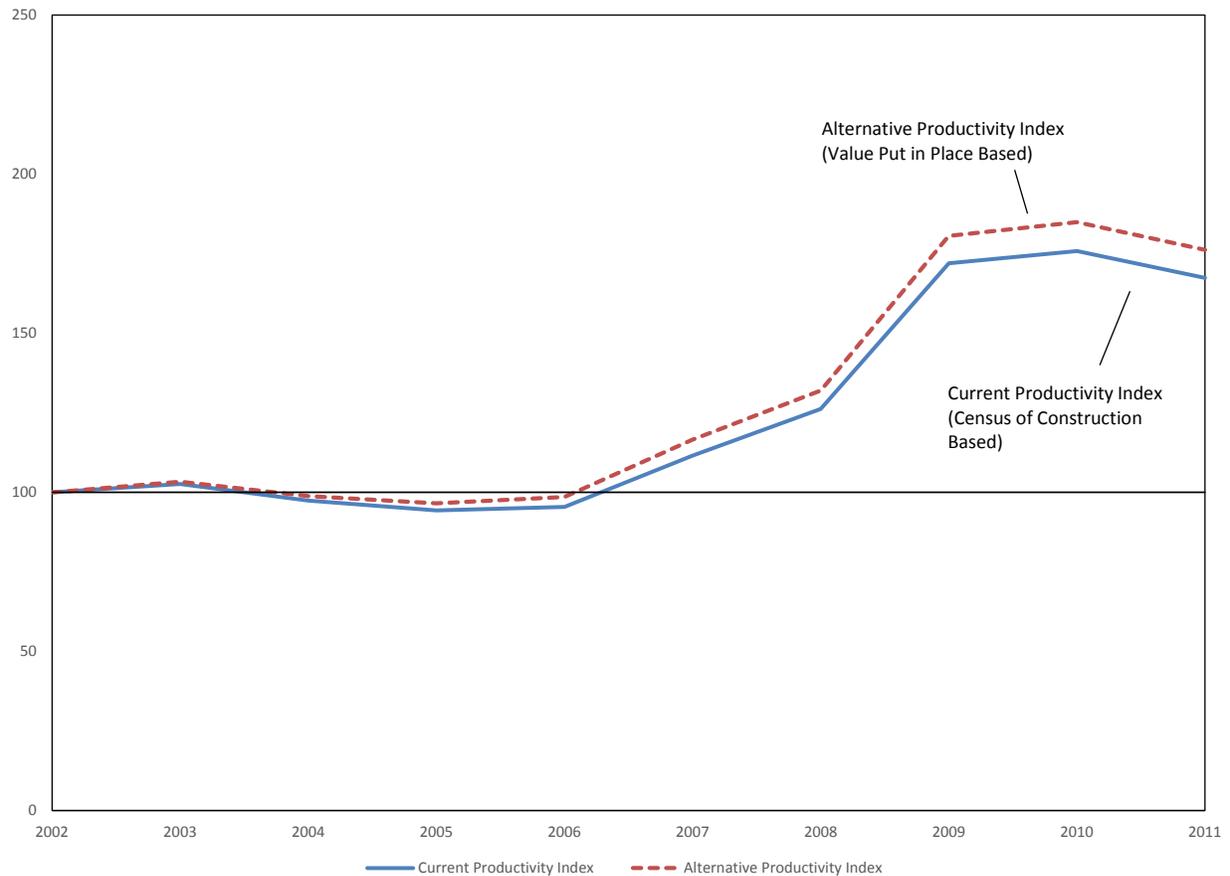


Figure 10 Labor Productivity, Streets, Highways and Bridges, Alternative Measures of Output.

In both Figure 8 and Figure 9, the peak index of labor productivity is very much greater when the measure of output is obtained from the Census of Construction.

How can we understand these differences between the Census of Construction and the Value Put in Place series? If we look at the underlying concepts more closely, the Census of Construction is collected on an establishment basis, which means that the data for each producer are assigned to an individual establishment and then every establishment is assigned to a specific industry.²² In contrast, the Value Put in Place data are primarily collected from lists of construction projects and measure actual expenditures on any given type of construction. An establishment is the continuing location of a firm,

²² Calabria (1998) mentions that the establishment data are obtained from the Bureau's Standard Statistical Establishment List (SSEL). The SSEL is a portion of the Census Business Register. Calabria also provides a useful description of the Census of Construction which, despite its name, is not a full Census. The Census of Construction is based on a complete count of relatively large establishments, but samples only a smaller proportion of less influential establishments.

such as its office or payroll location. A project is the location of a construction site, and changes much more frequently.²³

The establishment data differ from project data because of secondary products. For example, some establishments assigned to residential housing also produce secondary outputs such as roads and streets. Conversely, establishments assigned to completely different industries, such as Real Estate, may also conduct some work within construction, such as apartment rental firms which build their own apartment buildings.²⁴

Almost all measures of industry output or productivity are prepared from establishment data. Therefore, there is a strong presumption that establishment data, such as those provided by the Census of Construction, should be preferable for our purposes. In addition, as we have noted repeatedly, when output and input data are collected from the same establishments, productivity measures are consistent. In contrast, there is no way of obtaining equivalent data on labor, capital, and materials inputs to match the output data collected on a construction site basis.

The Census Bureau takes no official stand on whether the Census of Construction or Value Put in Place output data are superior. In addition, it has proven difficult to reconcile these series, especially over time. Since the underlying source of information and the sampling frames differ, it is not surprising that results from the two procedures sometimes diverge. Blum (1980), an analysis of 1977 data, is probably the best effort to understand differences between these series. In addition, Cole (2002) compared the two series in 1997.²⁵

²³ In addition to differences in the sampling frame, Census of Construction data on output reflect the price at which construction output is actually sold, while Value Put in Place data, which are collected monthly, measure the price which builders anticipate when their production is completed and reported. If builders systematically underestimate cyclical variation in output prices, Value Put in Place data may, for this reason, understate the true variance in construction expenditures which occurs over the cycle. In addition, asking prices frequently overstate the actual price at which construction projects are eventually sold.

²⁴ Blum (1980, p. 166) points out that many investment builders derive most of their income from rent so that the Census (accurately) classifies them in Real Estate rather than in Construction. As Blum mentions, this issue is particularly important in multifamily housing. Firms which operate apartment buildings or hotels and motels often construct their own buildings.

Another important way in which the Census differs from the Value Put in Place data occurs when manufacturers or stores use their own resources (own account construction) to construct or modify a building. Such construction activity appears in the Value Put in Place series, but is not included in the Census of Construction because these establishments, too, are classified as outside construction.

²⁵ Blum (1980) and Cole (2002) both attempted to reconcile the Census of Construction and Value Put in Place data on a cross-section basis. It is even more challenging to attempt to resolve the differences between the series in time-series data.

Our attempts to reconcile the time-series data have not been successful. For example, we thought that most of the growth in the Value Put in Place housing data might have occurred among builders, while establishments classified in Real Estate were more stable and grew more slowly. If true, such circumstances could have explained why output grew more rapidly in the Census of Construction data, which exclude firms classified in Real Estate, than in the Value Put in Place data. However, the data on construction expenditures show that construction

IIC. Measures of Productivity Growth Which Include Subcontractors in Labor Input.

The measures of productivity growth analyzed in Sections IIA and IIB measure labor input as the hours directly employed in each industry. However, in many industries, especially single and multiple family residential construction, firms often obtain substantial labor inputs indirectly, as part of a larger package purchased indirectly from subcontractors. Section IIC estimates the labor input obtained from subcontractors and includes subcontractor hours as part of overall labor input.²⁶

Table 7 of the Industry Volumes of the 2007 Census of Construction shows how much output contractors in each field (such as plumbers or electricians) deliver to each type of construction (such as single or multiple family residential construction).²⁷ In addition, this same table indicates how much output is delivered to each type of construction for new construction, for additions, alterations, and renovations, and for maintenance and repair.

One key point is that, in residential housing, additions and alterations and maintenance and repair are all included in NAICS 236118, residential remodelers. Contractor deliveries to additions and to maintenance therefore do not affect our estimates of productivity growth in the single and multiple family categories, which cover only the new construction reported in NAICS 236115, 236116, and 236117.

To determine how much labor contractors deliver to builders in the residential industries, we use the following procedure. We assume that subcontractor deliveries (of output) for additions and alterations are twice as labor intensive (have twice the labor/output ratio) as deliveries for construction. Similarly, we assume that output delivered for maintenance and repair is three times as labor intensive as output provided to construction. These assumed ratios hold true for every type of contractor and for deliveries to each type of construction.

spending by Real Estate firms increased remarkably quickly from 2002 to 2007, so that this hypothesis does not fit the facts.

²⁶ Subcontractor labor is normally allowed for by including purchases from subcontractors as materials input in calculations of multifactor productivity growth. In view of the substantial difficulties inherent in calculating MFP in construction, as outlined in Section IID below, it seems advisable also to prepare alternative measures which include subcontractor labor as a portion of labor input.

²⁷ Table 7 is entitled "Value of Construction Work for Establishments by Type of Construction". Note that Table 7 refers only to establishments with payroll. We develop measures of the further labor input provided by establishments without payroll in each subcontractor industry, and assume that these further hours are provided to using industries in the same proportions.

Given these assumptions, we can determine how much of the labor supplied by a particular type of contractor, perhaps carpenters, is allocated to each of these different facets of production. Assume for example that carpenters supply 60 percent of their total output (deliveries to all sectors, not just to home building) to new construction, 20 percent to additions and alterations, and another 20 percent to maintenance and repair. In conjunction with the labor/output ratios of 1, 2, and 3, we can state that:

$$0.60 \cdot 1x + 0.20 \cdot 2x + 0.20 \cdot 3x = L$$

where L is the total labor input employed by the carpenters.

Solving this particular equation for x, we can see that $x = L/1.60$, or that the total amount of labor carpenters supply to new construction is $0.60/1.60 L$, so that approximately 0.375 of all carpenter subcontractor labor is delivered to new construction, after allowing for the relative importance, and labor intensity, of new construction, additions and alterations, and maintenance and repair. Once we know how much labor is delivered to new construction, we can allocate construction labor to the specific industries which utilize this. For example, if 80 percent of carpenter labor deliveries to new construction is supplied to single family home building, we can calculate that 0.80 times 0.375, or 30 percent of all carpenter contractor labor is supplied indirectly to single family home building. Once we calculate how much labor carpenters, plumbers, roofers and every other type of contractor supply to single family housing, we simply take the contributions from each craft and sum these up to determine the total amount of indirect labor provided by contractors. An entire set of such calculations is performed separately for each Census year.²⁸

Figure 11 compares the growth of direct and indirect (subcontractor) labor in single family housing. Figure 12 reports similar information for multiple family housing, while Figure 13 shows corresponding trends for highways, streets, and bridges. Note that, unlike housing, in highways all the labor measures include additions and alterations and maintenance and repair, as well as new construction.

²⁸ Some readers have been concerned about the arbitrary weights attached to each type of construction in the above calculations. To examine the sensitivity of these assumptions, we also calculated the overall growth of labor input using weights of 1.0 for new construction, 1.5 for additions and alterations, and 2.0 for maintenance and repair. By giving less weight to additions or maintenance, these calculations assign more subcontractor labor to new construction. However, the alternative assumption increases overall total labor input growth by only 0.1 percent per year or less.

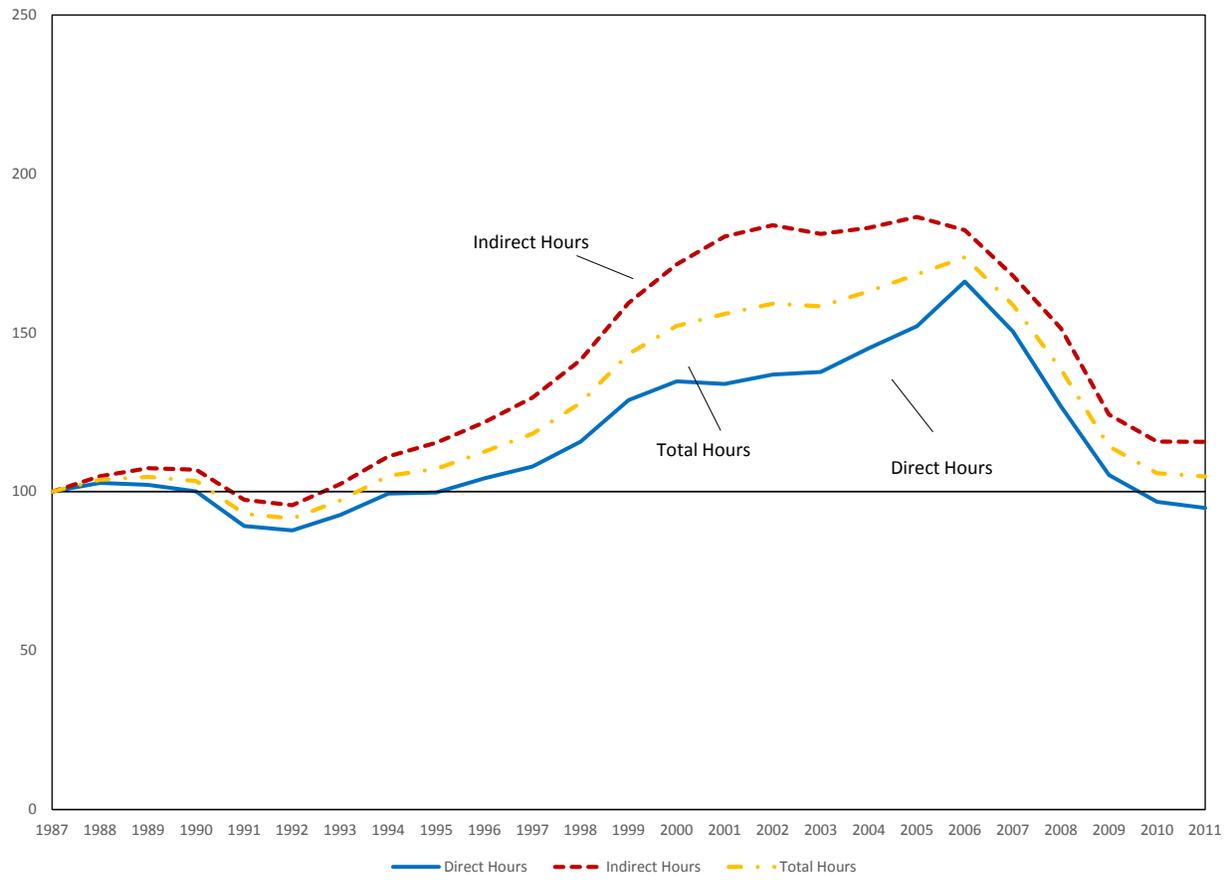


Figure 11 Single Family Residential Construction: Direct Labor, Indirect Labor, and Total Labor Inputs.

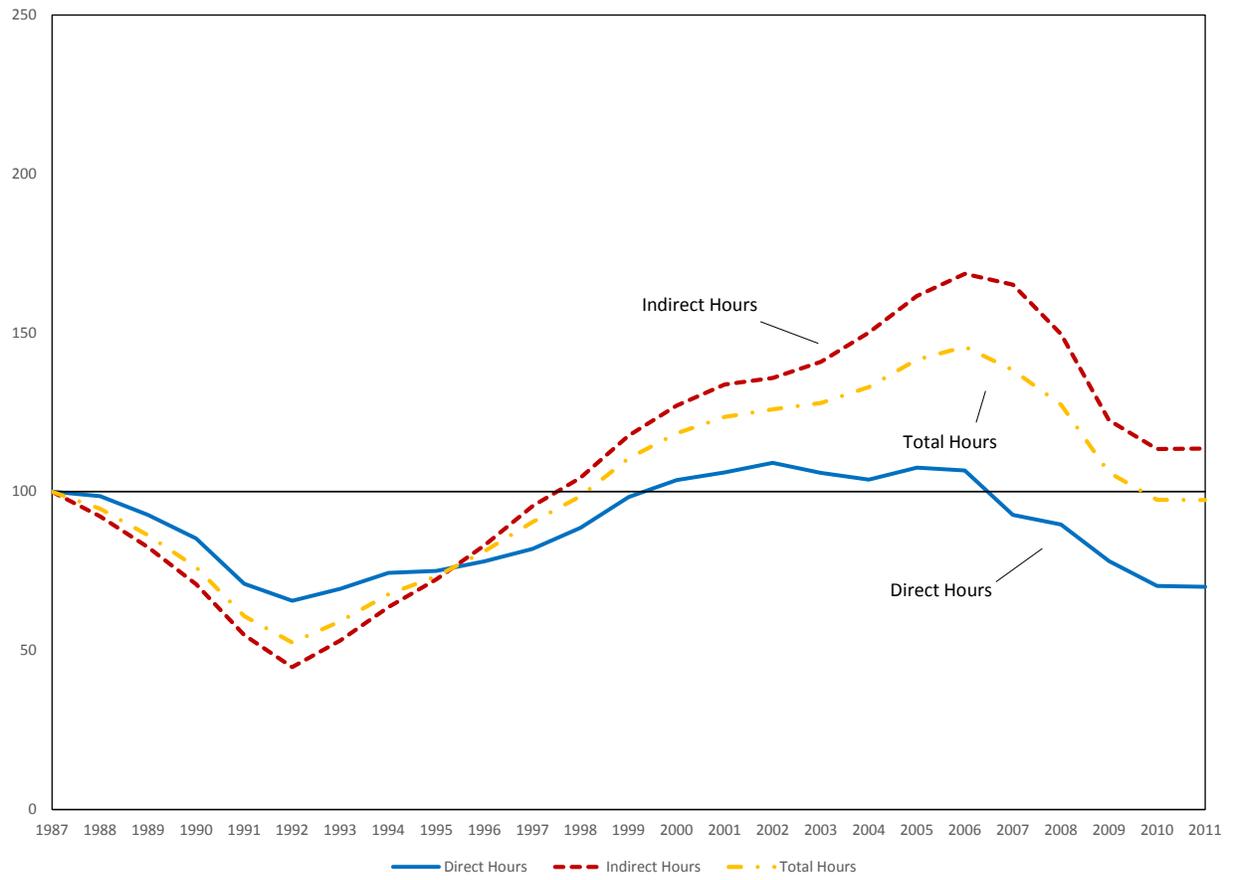


Figure 12 Multiple Family Residential Construction: Direct Labor, Indirect Labor, and Total Labor Input.

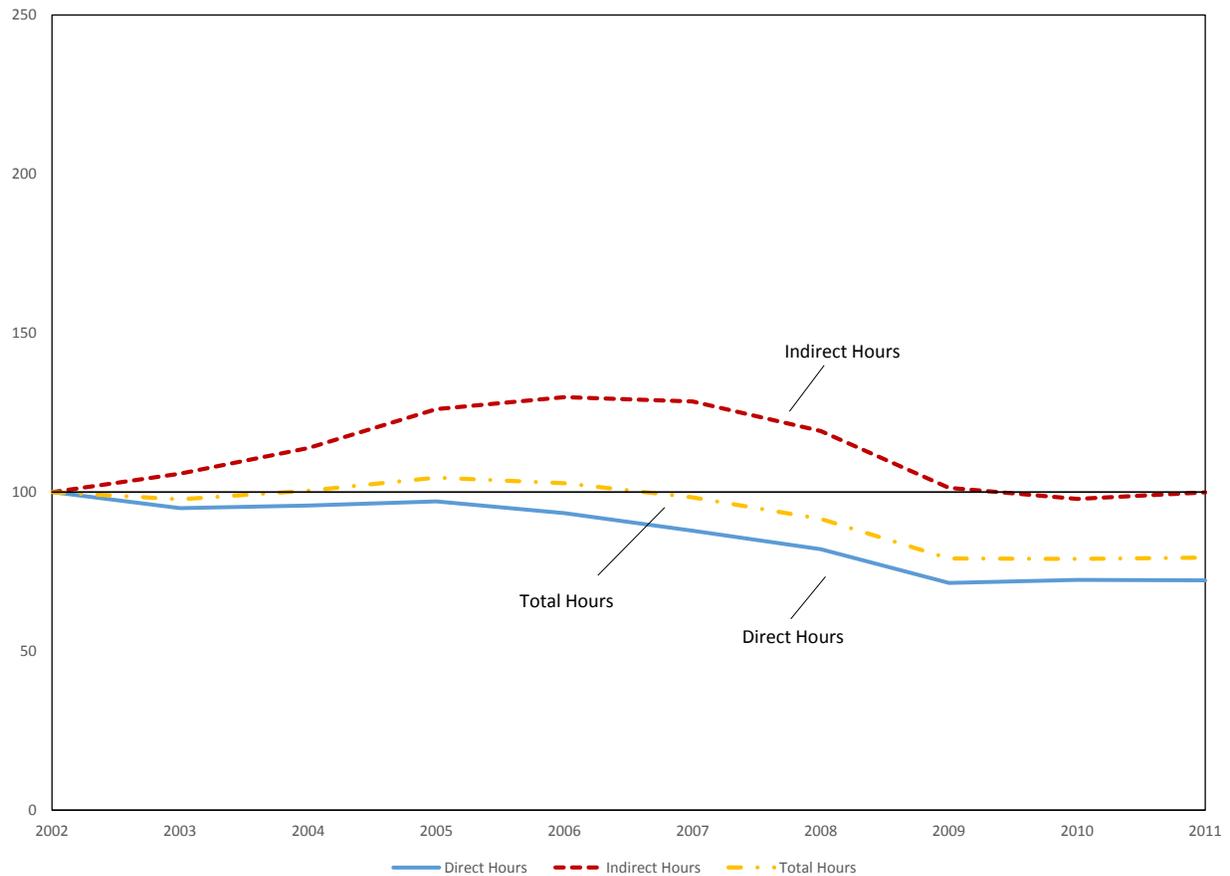


Figure 13 Highways, Streets, and Bridges: Direct Labor, Indirect Labor, and Total Labor Input.

As Figures 11, 12, and 13 indicate, in each of the three industries indirect hours (subcontractor hours) increase more rapidly than the labor directly employed in the industry.²⁹ As a consequence, in all three cases, if total labor is defined as direct plus subcontractor hours, total labor increases more rapidly than direct hours, so that the implied rate of labor productivity growth is lower.³⁰

Table 3 reports specific values of productivity growth rates when the alternative measure of labor input is used. As Figure 11 suggests, in single family housing including subcontractors in labor input results in a modest decline in labor productivity growth. On the other hand, when subcontractors

²⁹ Such results imply that, over time, builders have substituted subcontractor labor for their own labor. If better information on subcontractor output prices were available, it would be possible to determine whether builders rely more heavily on subcontractors over time because subcontractor productivity has increased more rapidly.

³⁰ In Figures 11, 12, and 13, whether overall labor productivity is closer to direct labor or indirect subcontractor labor depends on the relative magnitude of these two labor forces. In 2007, direct labor accounted for 49.8 percent of the total hours involved in single family construction. In multiple family, direct labor was 24.8 percent, and in highways 66.3 percent.

are included labor productivity in multiple family housing and in highways drops somewhat more sharply.

What conclusions can we draw from including subcontractors as labor input? Overall, as Table 3 shows, productivity growth is lower in all three industries once subcontractors are included. However, the basic theme that long-term productivity growth, adjusted for the business cycle, is positive still holds true in the adjusted data.³¹ Productivity growth is clearly positive in multiple family homes and in highways. In addition, though productivity growth in single family housing is not significantly greater than zero, our best point estimate for this industry still suggests a positive productivity trend.

Table 3 Labor Productivity: Effect of Alternative Labor Input Series on Labor Productivity Growth.

Panel A	1987-2011		1997-2007	
	Average Annual Rate of Change		Average Annual Rate of Change	
Type	Standard	Standard + Subcontractors	Standard	Standard + Subcontractors
Single Family	-1.4%	-1.8%	-0.2%	0.2%
Multifamily	-0.2%	-1.5%	5.7%	2.5%

Panel B	2002-2011	
	Average Annual Rate of Change	
Type	Standard	Standard + Subcontractors
Highways, Streets, and Bridges	5.9%	4.8%

Figures 14, 15, and 16 describe the annual productivity behavior summarized in Table 3, which is once again useful in describing the peak levels of productivity observed in the boom years. As was the case with the hours data summarized in Figure 12, multiple family residential productivity, described in Figure 15, is most substantially affected when indirect hours are also included in labor inputs.

³¹ We correct for cyclical influences by using housing starts as an additional independent variable, as in footnote 20. Empirical results when L includes subcontractor labor are:

For single family residential construction

$$\begin{array}{l} \log(O/L) = -2.55 + 0.488\log(\text{Housing Starts}) + 0.0024\text{time} \\ \text{t ratios} \quad (-0.77) \quad (15.31) \quad (1.49) \end{array} \quad \bar{r}^2 = 0.919$$

For multiple family residential construction:

$$\begin{array}{l} \log(O/L) = -28.68 + 0.342\log(\text{Housing Starts}) + 0.0160\text{time} \\ \text{t ratios} \quad (-2.40) \quad (3.78) \quad (2.73) \end{array} \quad \bar{r}^2 = 0.394$$

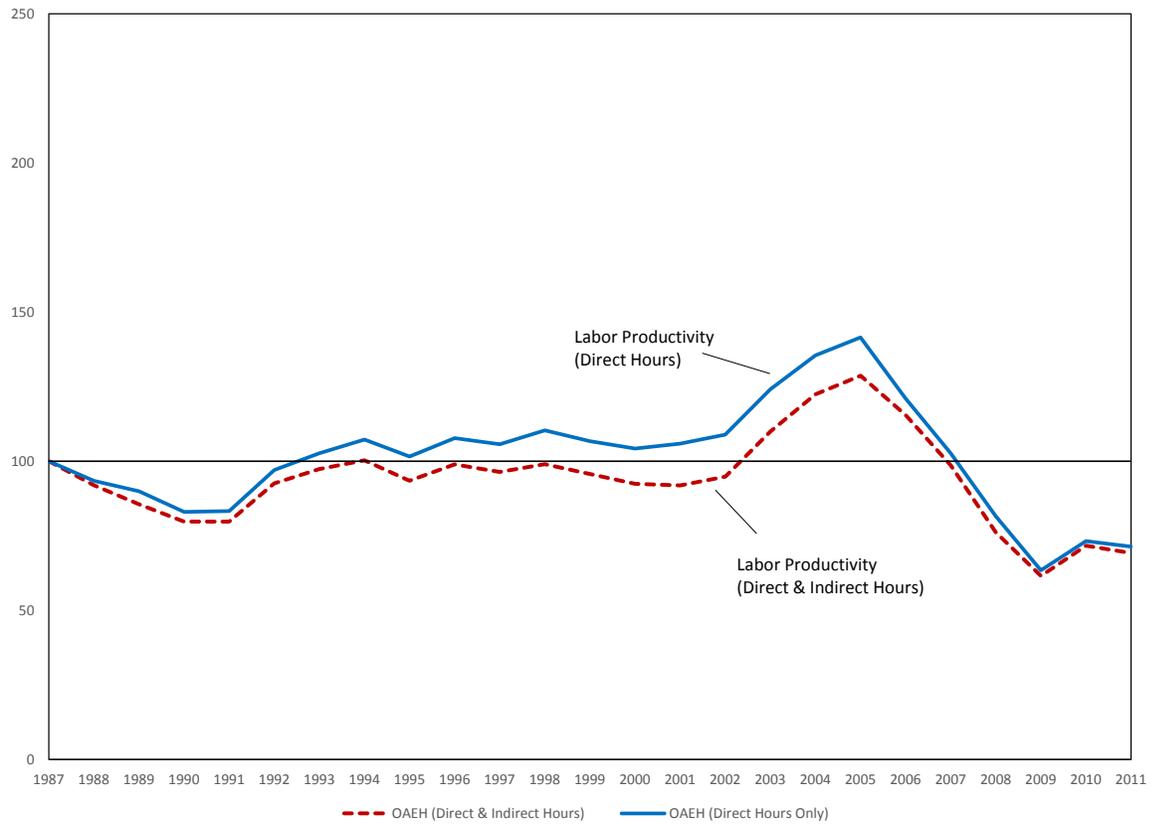


Figure 14 Labor Productivity Single Family Construction, Direct and Indirect Hours

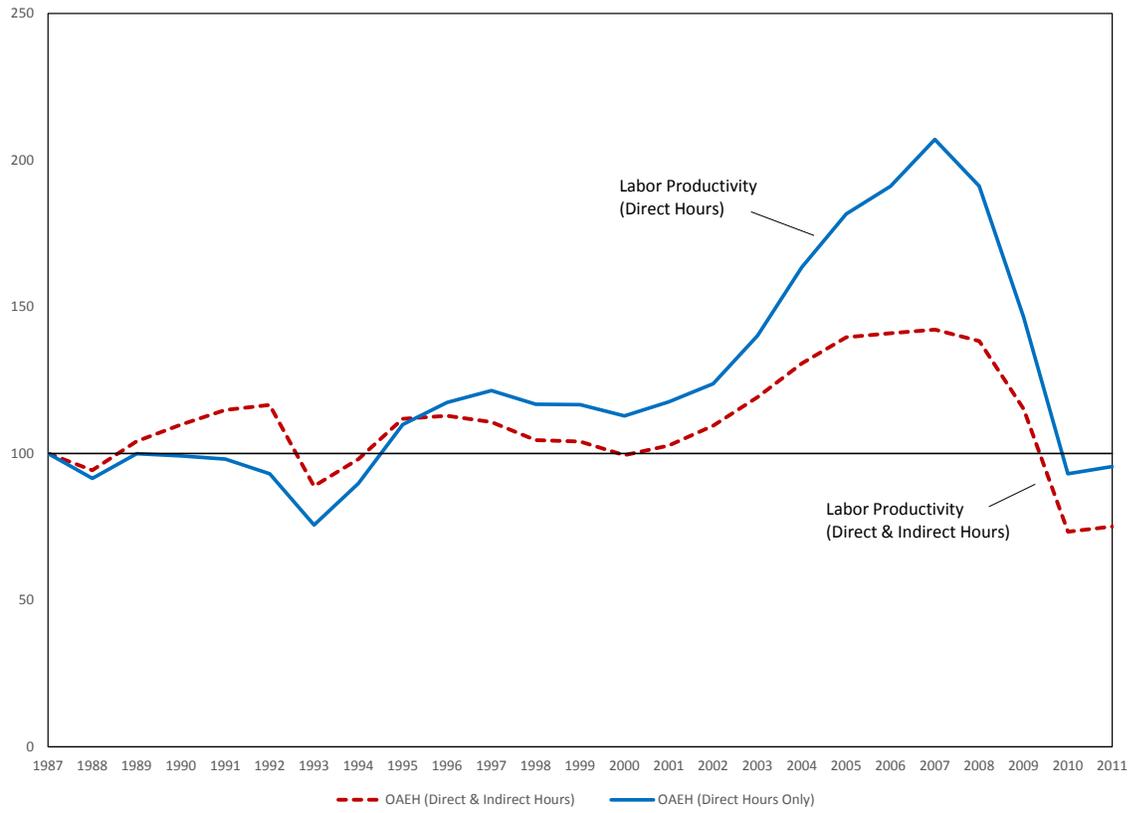


Figure 15 Labor Productivity Multiple Family Construction, Direct and Indirect Hours

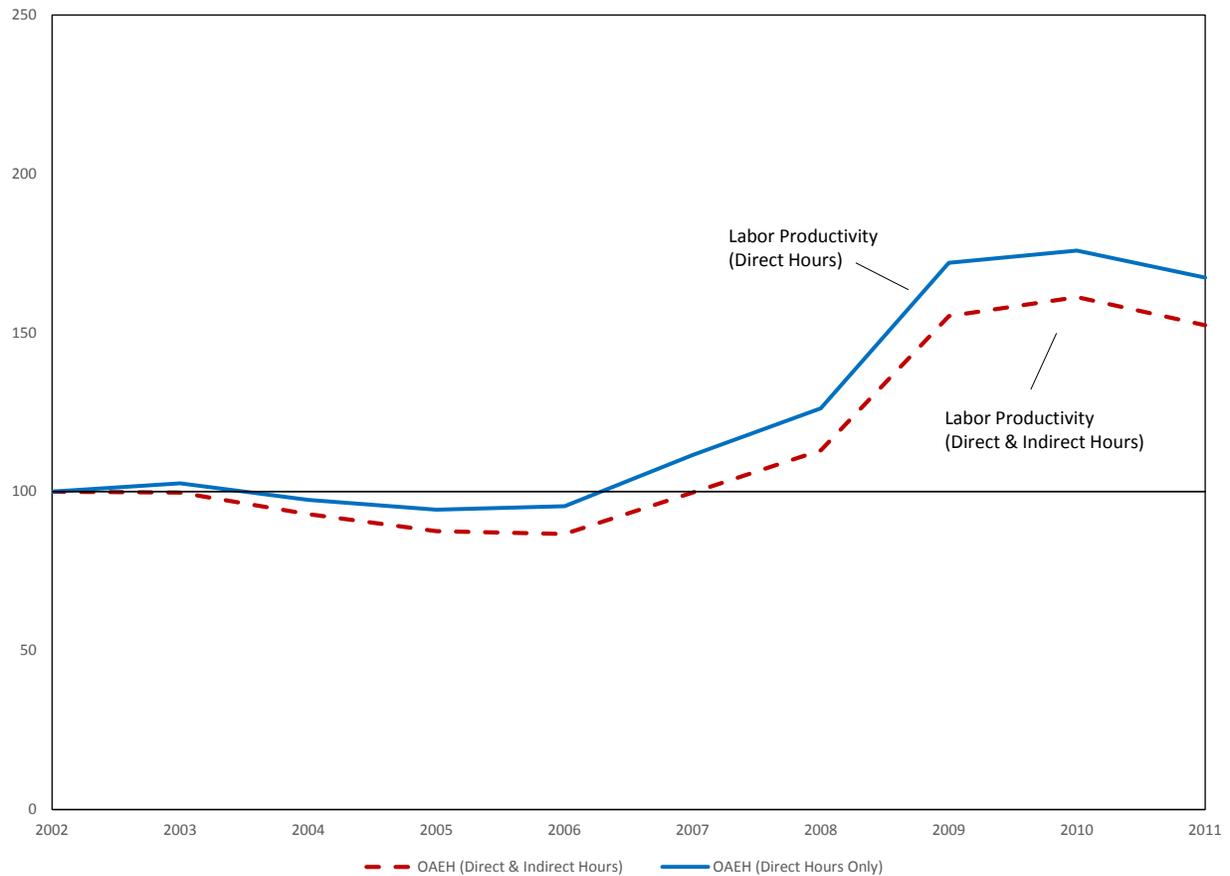


Figure 16 Labor Productivity, Highways, Streets, and Bridges, Direct and Indirect Hours

IID. Measures of Multifactor Productivity Growth in the Three Industries.

Section II has so far concentrated on measures of labor productivity growth within each of our three industries. Section IID examines whether it is possible to prepare estimates of multifactor productivity growth within these same industries.

Two main types of problems arise in measuring multifactor productivity within these industries. First, a variety of issues occur in calculating materials inputs and prices. Second, not much data is available to estimate capital inputs and prices; in particular, the available data show only investment in plant and in equipment, and even that information exists only for Census years. Despite the substantial difficulties involved, we think that it will eventually be possible to prepare rough, approximate, but still useful measures of multifactor productivity growth.

Several issues make it difficult to determine materials inputs in construction industries. In most of the economy, Bureau of Economic Analysis input-output tables report materials purchases for each NAICS industry. Once a list of the appropriate inputs is in hand, it is a relatively easy matter to determine the price and quantity of materials inputs used by each industry. However, in construction, the Bureau of Economic Analysis reports the input-output table on a final demand basis rather than on a NAICS industry basis. The columns of the input-output table refer to final products such as single family homes or warehouses. Under these circumstances, it is difficult to determine whether materials purchases have been bought by builders or by contractors. For example, we cannot determine whether a hot water heater in a house was bought by the builder or by a contractor.

In addition to this fundamental difficulty in knowing the specific materials inputs purchased by each NAICS industry, it is sometimes difficult to price several of the inputs to construction industries. Input prices are readily available for standard input items such as concrete, lumber, and plumbing supplies. It is more difficult to measure the input price for materials purchased from contractors, since we do not have reliable price deflators for many contractors; nevertheless, the PPI now does provide at least some reliable information on contractor prices, such as the price index for electrical contractors, except residential.³²

A third area of difficulty occurs with purchased business services. In many cases, builders formerly purchased labor and other inputs themselves, but now frequently purchase an equivalent bundle of inputs from an outside supplier. This sort of outsourcing often shows up in the data as the purchase of services. A builder may purchase \$50,000 worth of services from one supplier and \$100,000 from another supplier. Unfortunately, we often do not know enough about exactly what is included in these many purchased services.³³ In some cases, purchased business services may represent another form of indirect labor purchases. In many instances, suppliers may provide builders with the labor of undocumented immigrants or of domestic workers similarly working off the books.³⁴ In other cases, business services may consist of materials or genuine business services. In the absence of reliable information on the content of purchased services, it is very difficult to price purchased services or to determine the extent to which they replace labor inputs.

Despite these various issues, we believe it is possible to prepare a rough estimate of materials inputs into each of our industries. Future work will outline the methodology to be used and the results which emerge.

³² In Section IIIA below we argue that we cannot assume that the same output price is relevant for residential and nonresidential contractors. This is because potential errors in output prices have a drastic effect on measures of output and productivity growth. On the other hand, contractor materials represent only one portion of materials inputs, and many other materials prices are measured well. Therefore, contractor prices have a greater impact on estimates of output growth than on materials inputs.

³³ Such difficulties with purchased business services occur in many industries, not just in construction.

³⁴ Section VB below examines whether standard establishment data, the traditional basis for productivity measurement, systematically understate the employment of undocumented immigrants.

Further difficulties occur within the data for capital inputs. The major problem is lack of sufficient detailed data on capital investment. The Census of Construction reports information on investment in structures and related facilities, and in machinery and equipment for each detailed industry. In recent years, the machinery and equipment data include detailed information for the autos and trucks subcategory. However, there is little information on capital investment by industry in the intervening years between Economic Censuses. The American Capital Expenditures Survey (ACES) does provide annual information on capital investment, and in plant and equipment separately. However, in construction ACES covers only three broad industries, building (which includes housing), heavy construction, and contractors. In addition, the ACES data begin only in 1994. Since there not enough investment data, and no breakdown by assets, it is not possible to measure capital stocks through a standard perpetual inventory approach.

The crucial question then is how well the detailed data which are available for Census years can approximate the true capital values obtained through full perpetual inventory calculations. Fortunately, work conducted at the Center for Economic Studies at the Census suggests that in manufacturing gross book value figures similar to those published in the Census of Construction can, if suitably adjusted for price change, provide a reasonable approximation to the capital stocks obtained through perpetual inventory calculations.³⁵ We will therefore use methods closely similar to those which have proved to be useful in manufacturing to develop estimates of capital stocks in construction.³⁶

The prevalence of rental capital is a further difficulty which arises in the measurement of capital in construction. As Table 4 below indicates, rental capital is quite important in construction.

Table 4 Importance of Rental Capital in Construction (in millions)

NAICS	Title	Rental Capital (\$millions)			Capital Expenditures
		Rentals	Machinery	Buildings	
23	Construction	24576.5	15431.6	9144.9	23855.5
236115	New Single Family Housing	510.9	157.7	353.1	606.4
236116	New Multifamily Housing	172.6	91.0	81.6	288.9
236117	New Housing For-Sale Builders	887.2	166.9	720.3	1827.0
237310	Highways, Streets, and Bridge	2679.3	2177.6	501.6	3208.4
31-33	Manufacturing	29248.2	8867.2	20381.0	158837.7

Sources: 2007 Census of Construction and 2007 Census of Manufactures. Data on construction investment exclude the value of land.

³⁵ As Drucker and Feser (2007, p. 40) indicate "Measures of capital based on current assets have been shown to perform well in micro-level research using the Longitudinal Research Database."

³⁶ Foster, Haltiwanger and Krizan (2001) adjust gross book value for inflation by multiplying book value by the ratio of constant dollar capital stock divided by the current dollar book value, as determined for each industry from BEA capital stocks; we will adopt their correction. Note that, in addition to the gross book value of depreciable assets, the Census of Construction also reports the value of inventories and rental expenditures for equipment and for structures, separately, for each establishment in each Census year.

As Table 4 shows, expenditures on capital rentals are approximately as important as gross investment in construction in total. As might be expected, rentals of buildings are particularly important in housing, whereas machinery rentals are more important in highway construction. Rentals play a much less substantial role in manufacturing.

To the extent that it is more difficult to track rental capital, as opposed to fixed assets, the importance of capital rentals in construction makes it more difficult to measure capital inputs. In addition, data on capital rentals, like data for gross investment, are available for individual industries only within Census years. Furthermore, the American Capital Expenditures Survey, which reports capital expenditures for industry groups for years between Census years, contains little information on rental payments for capital.³⁷ Therefore, there is little chance of calculating capital rentals between Census years. However, the Census of Construction does report detailed information on capital rentals, for both equipment and structures; we shall follow Drucker (2012, p. 35) in using service prices to convert these measures of rental payments into capital stocks for Census years.

Despite the many difficulties outlined here, further work will measure multifactor productivity growth in each of these three industries. Work on these three industries will in a sense represent a prototype. Progress in measuring multifactor productivity growth in these three industries will later be the basis for comparable efforts in additional construction industries.

III. Measures of Productivity Growth Outside the Three Industries.

Section II examined productivity growth in three industries. Even though the three industries, especially single family residential construction, are important, these three industries account for only a portion of total construction. In addition, our three industries are not widely representative. They cover a lot of residential construction, but not much of heavy construction (only highways) and nothing at all of contractors. What then can we say about productivity growth in all the rest of construction? Section III examines information on productivity growth in other portions of construction.

Section IIIA considers productivity growth in eight further industries for which the PPI now provides improved output price deflators. These industries comprise four types of buildings (warehouses, schools, offices, and industrial construction, listed according to the order in which the PPI began to publish the new series) and four kinds of contractors (concrete, roofing, electrical, and plumbing heating and air conditioning contractors).³⁸ As explained in Section IIIA, we will have to obtain access to data on individual establishments within the Census of Construction in order to prepare productivity numbers consistent with the industry boundaries of these eight new PPIs.

³⁷ ACES does report annual expenditures on long-term leases of new capital assets, but long-term leases are only a small proportion of overall capital rentals.

³⁸ It is important to emphasize that all the PPIs for contractors refer to only the nonresidential component of each contractor industry.

For many years BEA had to use approximate deflators, such as a combination of one-half the Turner Construction Cost index and one-half the single family residential construction deflator, in order to deflate output in many aspects of construction. The old ineffective deflators are still in use for some components of construction, such as leisure construction or religious construction. From about 2005 to the present, we can therefore compare output growth under the new PPI deflators with output growth under the old ineffective deflators. Such comparisons can help us understand what was probably occurring in the construction data during the many years in which large amounts of output had to be deflated by inferior deflators because the new improved PPI deflators were not yet available. Section IIIB examines these issues.

IIIA. Measures of Productivity Growth in Further Industries: The Census Microdata.

For many years it has been difficult to prepare measures of productivity growth in construction and in specific construction industries because there are no reliable measures of output price deflators for these industries. Recently, however, the PPI program has produced high-quality estimates of output price for a variety of construction industries.³⁹ The new improved deflators cover warehouses, schools, offices, and industrial construction, and the nonresidential component of concrete, roofing, electrical, and plumbing heating and air conditioning contractors.⁴⁰

The Census of Construction publishes data for each existing NAICS industry. However, the newly available PPI deflators generally do not match NAICS industries. As Table 5 below indicates, most of the new PPIs are more narrowly defined than the published NAICS industries.

³⁹ The new improved PPIs are not based on actual construction prices. Instead, following the lead of the Canadian and Australian statistical agencies, BLS establishes a typical building for each of four areas of the country. They then price the cost elements for these typical buildings. In addition, the Bureau surveys builders monthly to determine the gross margin charged above observed costs. Harper (2014) provides a detailed description of the methods which BLS uses to prepare these new PPIs in construction.

⁴⁰ In addition to the eight industries mentioned in the text, the PPI currently also publishes measures for two further industries in construction. The first is new health care building construction, which covers both hospitals and medical offices. The medical construction index begins only in June 2012. We will not be able to include medical construction in the present study because we need two Census years to benchmark productivity measures for new industries. Productivity measures for medical construction can be prepared after the 2017 Census.

The new PPIs also cover maintenance and repair in nonresidential construction. The Census of Construction does report expenditures on maintenance and repair for individual industries. However, there is no actual information on the corresponding labor inputs used in maintenance and repair. Therefore, we cannot prepare a productivity measure for maintenance and repair.

However, as mentioned on page 39 of the text, if we can access the micro data at the Census, we can determine which establishments in any industry specialize in new construction, additions and alterations, or maintenance and repair. We can then measure the labor inputs devoted to maintenance and repair, which opens up new possibilities of computing levels and rates of growth of labor productivity for maintenance and repair construction in each industry.

Table 5 PPI Coverage and the NAICS Industries for Which Productivity Series Exist.

PPI Coverage		Corresponding NAICS Industries	
PPI	Description	Month/Year Start	Industry Description
236211	New industrial building construction	Jun-06	236210 Industrial Building Construction
-	-	-	236220 Commercial and Institutional Building Construction
236221	New warehouse building construction	Dec-03	236220 pt Warehouses
236222	New school building construction	Dec-04	236220 pt Schools
236223	New office building construction	Jun-05	236220 pt Office Buildings
236224	New health care building construction	Jun-12	236220 pt Health Care Buildings
-	-	-	236220 pt Stores, Restaurants
-	-	-	236220 pt Religious Buildings
-	-	-	236220 pt Hotels, Motels
-	-	-	236220 pt Public Safety (Prisons, Police, Fire)
-	-	-	236220 pt Amusement, Social, and Recreational
238113	Poured concrete foundation and structure ctrs, nonresidential	Jun-07	238110 Poured Concrete Foundation and Structure Contractors
238163	Roofing contractors, nonresidential	Jun-07	238160 Roofing Contractors
238213	Electrical contractors, nonresidential	Jun-07	238210 Electrical Contractors
238223	Plumbing, heating, and AC contractor, nonresidential	Jun-07	238220 Plumbing, Heating, and AC Contractors

As Table 5 shows, only for NAICS 236210, industrial building construction, can we simply obtain NAICS data from the Census of Construction and use the published Census data to prepare productivity measures consistent with the new PPI. In all the other cases, the new PPI is more finely detailed than even the most detailed NAICS industry. For example, the Census of Construction provides information only for the broad NAICS industry 236220, Commercial and Institutional Building. The new PPIs cover Warehouses, and Schools, and Office Buildings, but many other portions of NAICS 236220 such as Stores and Restaurants, Hotels and Motels, or Public Safety Buildings are not represented. Similarly, the Census of Construction covers NAICS 238160 which includes all roofing contractors, whereas the PPI covers only Roofing Contractors, except Residential which excludes the large number of roofers who work on residential homes. If we were forced to rely on published NAICS data to measure productivity, we could only prepare measures for the three basic industries considered in Section II plus industrial building construction. That amount of coverage would not be sufficient to understand the construction industry.

Under these circumstances, we believe we have no alternative but to go inside the establishment micro data of the Census of Construction to find exactly those establishments which produce warehouses, schools, office buildings, or Roofing Contractors, except Residential. The Census of Construction reports on all recognized NAICS industries. We will use the micro data to establish industries more detailed than the current NAICS, and collect information on output, employment, and the presence of partners and proprietors in smaller quasi-NAICs industries which produce exactly what the PPI is pricing. As Calabria (1998, p. 14) remarks in his analysis of Census of Construction data "Access to establishment level microdata allows the researcher a much greater flexibility when categorizing establishments".

The Census Bureau micro data report how much each establishment produces by each type of construction, so it is feasible to determine exactly which establishments specialize in warehouses, office buildings, schools, or electrical contractors except residential. Once the establishments associated with each type of newly defined smaller industry have been determined, it is an easy matter to cumulate the output, labor input, number of partners and proprietors, materials expenditures, and capital

expenditures applicable to each of these types of construction. Through these procedures, we can prepare, calculate, and publish new measures of the rate of productivity growth found in each newly defined industry consistent with the new PPIs.⁴¹

In addition, to the PPI values for the basic eight new industries, we may eventually be able to obtain further unpublished “research” deflators for several additional types of subcontractors. If this possibility works out, we will be able to include several additional industries in our analysis. In these further instances, we will not be able to release the values of the output prices deflators, but still hope to prepare estimates of productivity growth.

Our work with the establishment data at the Census Bureau cannot be completed until after the micro data from the 2012 Census of Construction are released to the Center for Economic Studies early in 2016. Once all the data have been analyzed, we will prepare estimates of productivity growth for each of the new industries mentioned in Section IIIA.⁴²

There is one further way through which access to the Census Bureau micro data can help us measure productivity growth in construction. These data report how much work each establishment produces in new construction, in additions and alterations, and in maintenance and repair. Each establishment can therefore readily be assigned to a single one of these activities. We can then estimate the level and rate of growth of labor productivity for each of these functions in each industry. The PPI price for each industry is actually a price for new construction. We can deflate the new construction portion of industry output by the PPI deflator to determine a productivity index for new construction within each industry. Similarly, in many cases, we can deflate estimates of maintenance and repair construction by the PPI deflator for maintenance and repair.⁴³ Such detail increases the number of potentially useful indexes we can prepare for each industry we consider. On the other hand, there is reason for caution. Before producing such additional measures, we will have to carefully examine the response rate for the data on new construction, additions/alterations, and maintenance/repair, which are obtained from the type of construction questions of the Census of Construction.⁴⁴

Overall, we think that further work measuring labor productivity growth and multifactor productivity growth from the Census micro data is warranted. The usefulness of these data illustrates

⁴¹ Of course, the Census establishes careful standards to safeguard against any disclosure of information for individual firms or establishments. In some of the smaller industries, disclosure issues may limit or prevent what can be published.

⁴² As Musgrave (1969, p. 771) comments about Census goals “The long-range goal of research currently underway at the Bureau is to develop adequate price indexes for each category of construction for which value of construction put in place estimates are derived”. Recent progress in the PPIs has at last made such goals attainable.

⁴³ There is no information on a deflator for additions and alterations. However, we plan to estimate such a deflator as a combination of the deflators for new construction and for maintenance and repair.

⁴⁴ In addition, every time we slice the data into smaller components, there is a greater possibility that disclosure issues will become important.

the way in which BLS production work can potentially benefit from access to Census micro data. In another example, Foster, Haltiwanger, and Krizan (2006) track down that productivity growth in retail trade essentially occurs through a shift towards big-box retailers; their work shows how BLS productivity concepts and numbers can be integrated with detailed micro data from the Census to provide a greater overall understanding of productivity growth.

PPIs for residential contractors.

We wish to make one further comment regarding the industries for which the new PPIs are now available. As the reader will have noticed, each of the contractor industries represented in the PPI, such as electrical contractors except residential, covers only the nonresidential components of a contractor industry. We have no information on output prices for contractors who serve residential construction. Different types of firms, with different characteristics, typically serve the residential and nonresidential segments of construction. Therefore, although sometimes we have no choice in the matter, it is quite a stretch to assume that the output price deflator is the same for the residential and nonresidential portions of a contractor industry.

We realize why the new PPIs are limited to nonresidential contractors. The fundamental purpose of the new PPIs is to contribute to the more accurate measurement of Gross Domestic Product. GDP is a crucial indicator, which any statistical system has to emphasize. By preparing output deflators for warehouses, schools, offices, and industrial construction, our PPI colleagues are contributing to the more accurate measurement of GDP.⁴⁵ Since accurate output price indicators already exist for single and multiple family residential construction, from this perspective further work on improving the deflators in the residential sphere is unnecessary.

At the same time, in order to measure productivity growth in our construction industries, it would be very helpful to obtain at least a few deflators for contractors engaged in residential construction, especially in such important areas as electrical work and plumbing, heating, and air conditioning. We understand that industry productivity considerations are a much lower priority than work which improves estimates of the GDP. Nevertheless, at some time in the future, it would be useful to prepare some high quality deflators for residential contractors, both to see how residential and nonresidential deflators differ, and to understand substitution between direct labor and subcontractor labor in residential construction more fully.

⁴⁵ Note that Bureau of Economic Analysis currently does not distinguish between new construction, additions and alterations, and maintenance and repair for warehouses, schools, offices, and industrial buildings, and simply uses the PPI deflator for new construction for all types of construction in these industries. (BEA combines additions/alterations and maintenance/repair and calls these improvements; however, they do not calculate a deflator for improvements in nonresidential construction, but use the deflator for new construction for improvements instead.) If we are able to progress beyond current procedures by calculating the proportion of output occurring in new construction, maintenance and repair, and additions and alterations within each of these four areas, and illustrating that separate deflators can effectively be used for each category, we may be able to make a modest contribution towards improving the accuracy of existing estimates of GDP.

IIIB. Measures of the Bias Associated with Poor Deflators.

As Section IIIA explained, the new PPIs for construction were essentially prepared to deflate construction activity more accurately for use in determining the Gross Domestic Product. From 2005 to 2007 new PPIs were introduced for warehouses, schools, offices, and industrial buildings. The Bureau of Economic Analysis has historically deflated expenditures in these four types of buildings by a deflator which represents the Turner Construction Cost index, with a weight of one-half, and the single family residential construction deflator, also with a weight of one-half. The Turner/single family index is still used to deflate some types of construction, such as construction for leisure activities, so values of this old generally inferior index are still readily available for recent years. Beginning in 2005, 2006, and 2007 the Producer Price Program prepared new output deflators for warehouses, schools, offices, and industrial buildings. The Bureau of Economic Analysis adopted these new deflators to price deliveries to final product (investment) for these types of buildings. Before these new PPI deflators were developed, BEA had deflated investment in these types of structures by the Turner/single family index. Values of the Turner/single family index are still available after 2005, since the old index is still used for certain facets of construction, such as construction for leisure or religious purposes.⁴⁶

How do these new more accurate PPI deflators compare with the less accurate approximations which were used in prior years? Table 6 presents evidence on this issue. The analysis examines price growth from the first quarter in which each new PPI was available until the last quarter of 2012. The evidence shows that, once the new PPIs were adopted, they increased considerably more rapidly than the old unreliable deflators. In fact, as column (5) shows, the new PPI deflators generally increased 2 percent per year, or more, than their old unreliable predecessors.

Many people have surmised that productivity growth in construction appears to be negative because deflators are poor.⁴⁷ However, Table 6 shows that, with the improved deflators, real output growth is slower rather than greater, so that implied productivity growth is even more negative. Such results suggest that output growth was overstated during the many years in which the Turner/single family index was widely used for deflation. Evidence of this sort makes it more likely that true productivity growth in construction has been negative over the long term.

⁴⁶ We use the values listed for line 26, Lodging, in BEA Table 5.4.4U, Price Indexes for Private Fixed Investment in Structures by Type, as our measure of the Turner/single family index. Line 4 of Table 5.4.4U corresponds to offices, line 12 to warehouses, line 14 to industrial buildings, and line 25 to schools.

Note that BEA uses the PPI deflator for these industries, which is based on new construction, for additions/alterations and maintenance/repair as well. Consequently, we can determine the values of the corresponding PPI deflators directly from the deflators for these types of structures. Similarly, BEA uses the Turner/Census deflator for lodging or religious construction, so we can determine the Turner/Census deflator directly from the deflator for these types of construction.

⁴⁷ As Pieper (1991, p. 260) states about historical data:

“The BEA still relies heavily on cost indexes and proxy indexes to deflate construction output. Price indexes are available for only two major construction sectors, single-family homes and highways. Partly as a consequence, it seems likely that the BEA deflator for new construction has a significant upward bias in the 1963-82 period.”

Table 6 Construction Output Prices from the New PPIs Compared with Their Predecessors

Type of Construction	Period of Coverage	PPI Growth	Old Deflator Growth	Growth Difference
Warehouse Construction	2005/1 to 2012/4	3.85%	1.78%	2.07%
Educational Construction	2006/1 to 2012/4	5.05%	0.58%	4.47%
Office Construction	2006/3 to 2012/4	2.64%	0.08%	2.56%
Industrial Construction	2007/3 to 2012/4	1.97%	-0.89%	2.86%

Note: The same Old Deflator (1/2 the Turner Construction Cost index and 1/2 the Single Family Residential Construction index) is used for each of the four types of buildings. The Old Deflator reported in the fourth column has different values for each type of construction only because the time periods differ.

In summary, between 2005 and 2012, the PPI deflators increased considerably more rapidly than the old inadequate deflators. In fact, with the better deflators, output prices increased two percent or more per year than with the old deflators. More rapid output price increases, in the context of an unchanged nominal expenditures series, implies that real output grew less. Such evidence suggests that output growth was probably overstated during the many years in which construction output was measured by poor deflators. Evidence of this sort indicates poor deflators are probably not to blame for the negative productivity growth often seen in construction. If more reliable deflators had been available, productivity growth would likely have been even more negative. The results from Section IIIB provide the strongest hint we have found that true productivity growth in construction may have been negative.⁴⁸

IV. Shifts Among Industries.

Allen (1985) concluded that, between 1968 and 1978, labor productivity growth was negative in the overall construction industry partially because low productivity portions of the industry were growing more rapidly. His evidence (p. 665) showed that industry shifts reduced productivity by 4.5 percent over the decade, which translates to approximately 0.46 percent per year. This section examines the role of inter-industry shifts by observing levels of labor productivity in 1987 and testing the hypothesis that labor inputs systematically grow more slowly in high productivity industries. The

⁴⁸ Of course, 2005 to 2012 is an atypical period in which a historic crash occurred in construction. It is possible that the atypical period could exaggerate the extent to which the PPI presents a different view of construction output.

Pieper (1991, pp. 246 to 248) emphasized that price indexes decline more rapidly than cost indexes when demand is weak. Nevertheless, the new PPI price indexes still increase more rapidly than cost indexes, even during the 2005-2012 period in which demand often declined sharply.

measures of growth of labor input always include partners and proprietors, who play a substantial role in many portions of construction.⁴⁹

To begin discussion of labor shifts, the 2007 Census of Construction reports data for 31 different five-digit or six-digit industries. We include NAICS industry 237210, land subdivision, even though this sector was classified as SIC 6552 in 1987. Table 7 lists the 31 industries which form the basis for analysis throughout this section.

Table 7 Industries Included in the Labor Shift Analysis, Shares of Hours, and Output per Hour in 1987.

Nominal Output per All Persons		Hours Shares		O/H
NAICS	Title	1987	2007	1987
236115	New single-family housing construction (except operative builders)	4%	4%	58524
236116	New multifamily housing construction (except operative builders)	1%	0%	109629
236117	New housing operative builders	3%	3%	129093
236118	Residential remodelers	5%	6%	44584
236210	Industrial building construction	2%	1%	58169
236220	Commercial and institutional building construction	10%	7%	96204
237110	Water and sewer line and related structures construction	2%	2%	50964
237120	Oil and gas pipeline and related structures construction	1%	2%	28758
237130	Power and communication line and related structures construction	2%	2%	37455
237210	Land subdivision	1%	1%	191056
237310	Highway, street, and bridge construction	6%	4%	58318
237990	Other heavy and civil engineering construction	2%	1%	51714
238110	Poured concrete foundation and structure contractors	3%	4%	35442
238120	Structural steel and precast concrete contractors	1%	1%	45085
238130	Framing contractors	2%	2%	23689
238140	Masonry contractors	4%	3%	25667
238150	Glass and glazing contractors	1%	1%	41388
238160	Roofing contractors	3%	2%	35447
238170	Siding contractors	1%	1%	29947
238190	Other foundation, structure, and building exterior contractors	0%	1%	35747
238210	Electrical contractors and other wiring installation contractors	9%	10%	35564
238220	Plumbing, heating, and air-conditioning contractors	11%	11%	41600
238290	Other building equipment contractors	2%	2%	44797
238310	Drywall and insulation contractors	4%	4%	39202
238320	Painting and wall covering contractors	5%	5%	19137
238330	Flooring contractors	2%	2%	28314
238340	Tile and terrazzo contractors	1%	1%	31595
238350	Finish carpentry contractors	4%	4%	20398
238390	Other building finishing contractors	1%	1%	32740
238910	Site preparation contractors	4%	8%	37580
238990	All other specialty trade contractors	3%	4%	32257
23	Construction	100%	100%	49587

⁴⁹ Partners and proprietors account for a considerable portion of labor inputs in construction. According to data prepared by the Division of Major Sector Productivity of the BLS, partner and proprietor hours accounted for 19.3 percent of the total hours in construction in both 2002 and 2007.

Shares of hours represent the proportion of total construction hours observed in each industry. Hours include partners and proprietors.

To understand the impact which labor shifts since 1987 have had on aggregate productivity⁵⁰, consider the following identity:

$$\overline{O/L} = \sum_{i=1}^{31} shl_i (O/L)_i \quad (3)$$

in which overall labor productivity, $\overline{O/L}$, is determined as the summation of labor productivity in each of the 31 industries, $(O/L)_i$, weighted by the share of overall labor input, shl_i , observed in each industry i . In order to understand the likely impact of shifts in labor inputs, we first calculate relationship (3) for 1987 using 1987 labor input weights for each industry. We then examine what 1987 productivity would have been if 2007 labor input weights were used instead. The difference shows how much lower output, and productivity, would have been in 1987 solely because of the labor input shifts observed by 2007. Such estimates provide a rough indication of productivity losses due to the shift in the distribution of labor hours observed between 1987 and 2007.⁵¹

Table 7 also reports the share of hours in each industry in 1987 and 2007 and measures of labor productivity, O/L , for each industry in 1987. The reader may note that Table 7 indicates that productivity is considerably higher in residential construction than in many other portions of construction, especially the contractors covered in NAICS 238. How does this square with Allen's (1985) contention that residential construction is much more labor intensive? Allen only considers the output of single family homes, office and industrial buildings, and educational and hospital buildings. Many contractors presumably work on home building, which increases labor intensity and reduces productivity in residential construction. We adopt an approach different from Allen's for two reasons. First, since we are interested in all of construction, we prefer to examine shifts among all 31 industries instead of selecting just a few of them. Second, we prefer to examine shifts in labor rather than shifts in output. The problem with framing the analysis in terms of output growth is that, since output deflators are not available, the output series mix true output and price changes, with these combined in unknown proportions.

Table 8 presents empirical results from equation (3). Over the full 1987 to 2007 period industry shifts reduced output appreciably. Labor shifts reduced output by 0.26 percent per year. This is a considerable impact, although not as great as Allen's estimate of 0.46 percent per year from 1968 to 1978.

⁵⁰ We examine labor shifts over time because, in the absence of accurate output deflators, it is not possible to measure output shifts accurately.

⁵¹ One could perform a similar exercise using 2007 productivity levels, examining the impact of the distribution of labor input in 1987 and in 2007. However, $(O/L)_i$ and shl_i in 2007 are jointly determined by many factors such as technology or demand conditions. For the purposes of a 1987-2007 analysis, it is preferable to treat $(O/L)_i$, as observed in 1987, as a predetermined variable.

Table 8 Index of Output Due to Shifts in Hours, 1987-2007, 1987 = 100.00.

	Implied Output in 1987
Year	Using Hours Shares
1987	100.00
1992	98.31
1997	96.68
2002	96.25
2007	95.01
Average Annual Rate of Change	-0.26%

Source: Estimates from equation (3b) using 1987 Values of O/L and shares of hours in each of the 31 industries. Hours include partners and proprietors.

Table 1 in Section I showed that labor productivity declines in construction were relatively modest from 1987 to 1997, perhaps in the range of -0.2 percent per year. However, the productivity decline was far more rapid in 1997-2007, in the range of -0.7 percent per year. In contrast, losses due to reallocation towards lower productivity industries were stronger in 1987-1997; in these years reallocation reduced labor productivity growth by 0.34 percent per year. However, during 1997-2007 the decline due to labor transfers was only 0.17 percent per year. Although industry shifts have a considerable impact, they do not do as well in explaining the timing of observed productivity declines.

Allen is correct that construction output shifted towards housing in 1968-1978. The present evidence indicates that labor shifts reduced construction productivity approximately 0.26 percent per year between 1987 and 2007. This is a considerable effect. However, industry shifts in themselves are not sufficiently great to provide a general answer as to why construction productivity has kept on declining, especially during the most recent 1997 to 2007 period.

Finally, we consider the difficult question of why construction labor may be shifting towards apparently lower productivity uses. In Allen's analysis, the critical point was that from 1968 to 1978 labor was shifting towards single family residential construction, which is more labor intensive than many other elements of construction. In Table 7 the housing industries still lose some labor share between 1987 and 2007, but the dominant shift instead represents a transfer of resources from heavy construction to contractors.⁵² Why would resources shift to lower productivity industries when resources much more typically flow from low to high productivity uses?⁵³ Perhaps small contractors, who are far less capital intensive, are more nimble and can be managed more effectively than the larger labor forces characteristic of heavy construction. Contractors may actually have greater overall

⁵² The shift towards housing documented in Allen (1985) also includes contractors involved in housing, so the increased prevalence of contractors does not necessarily conflict with Allen's shift to housing. Section IIC shows how allowance for subcontractors affects measures of housing productivity.

⁵³ One of our readers has commented that some sectors of heavy construction are especially dependent on government contracts. Many levels of government have faced strong budgetary constraints, so the decline in heavy construction may reflect such exogenous influences.

productivity. The only way to test this possibility and to understand the observed pattern of growth of different industries and the increased reliance on subcontractors, is to calculate measures of productivity growth for a large number of industries in construction, including many contractors. The work plan outlined in Sections IID and IIIA examines the possibility of producing such data.

V. Analysis of State Data.

VA. Regulation.

It is quite plausible that, when environmental regulations are binding, producers have to spend some resources meeting these obligations so that a smaller proportion of inputs is available to produce conventionally measured output (Greenstone, List, & Syverson, 2012). Similarly, it is reasonable that when environmental restrictions are greater, a greater proportion of inputs must be used to meet these requirements.

Ganong and Shoag (2012) developed an index of land use regulation in each state in each year. Their measure consists of the proportion of appellate cases in each state which use the phrase “land use”. This measure is cumulative in the sense that the total number of references to land use and the number of cases are updated each year; however, if new cases refer to land use less often, the cumulative measure can decline. Since an index of land use restriction based on legal practice might appear to be unconnected from actual building practice, it is important to note that Ganong and Shoag show that their measure of land use limits is correlated with prior measures of actual land use restriction in different geographic areas.⁵⁴

The Ganong-Shoag measure appears to be an excellent fit for construction. Land use law in all its ramifications limits housing development, office and store development, and many other forms of construction. This measure of regulation may also reflect broader environmental concerns. The existence of regulations will therefore limit observed productivity. Specifically:

$$\log(V/L)_{i,t} = a + b \log(Reg)_{i,t} \quad (4)$$

where $(V/L)_{i,t}$ is value added per unit of labor in state i in year t , and $(Reg)_{i,t}$ is the cumulative amount of regulations binding in each observation, as measured by the Ganong-Shoag index. Note that equation (4) is expressed in terms of real value added, $V_{i,t}$, rather than gross output, $O_{i,t}$, because BEA publishes data only on gross product originating, or value added, for the construction industry in each state.⁵⁵ The logarithmic form is selected because an increased amount of regulation, say a linear increase from 0.8 to 0.9, does not necessarily have the same impact as an increase from 0.1 to 0.2. The empirical data in fact do support the linear in logarithms form. The central hypothesis is that the

⁵⁴ r^2 between the Ganong-Shoag index and an explicit measure of regulation prepared in a survey conducted by the American Institute of Planners in 1975 is 0.23. r^2 between the Ganong-Shoag land use index and the Wharton Residential Land Use Regulation Index, prepared in 2005, is 0.36.

⁵⁵ Consequently, all estimates of the effect of regulation throughout this section refer only to gross product originating, which is a value added concept. No direct information is available on gross output productivity.

presence of regulations has a negative effect on observed productivity, so that $\hat{\beta}$ in equation (4) is negative.

In considering estimation of equation (4) across different states from 1977 to 2010, states with high levels of regulation are likely to differ from other states in many other characteristics as well.⁵⁶ It is therefore necessary to include a complete set of state fixed effects dummies in the analysis. This framework ensures that any effects attributed to regulation reflect genuine effects of regulation within the individual states rather than any external factors correlated with state characteristics. In addition, estimation should allow for time effects, either through a time trend or, more flexibly, through a complete set of time dummies.

Table 9 reports several estimates of the effect of regulation on labor productivity from pooled state and year data. Columns (1) and (2) report a linear form, in which $\log(Reg)_{i,t}$ determines $\log(V/L)_{i,t}$. In column (2) the time dummies perform far more strongly than the continuous time variable in column (1) in terms of explanatory power. All the rest of the analysis in Section IV therefore adopts the more flexible time dummy form. In this levels form, an F test clearly supports the inclusion of state dummies.⁵⁷ Column (3) examines a rate of change version, in which the rate of change of regulation, $\log(Reg)_{i,t} - \log(Reg)_{i,t-1}$, helps explain the annual change in productivity, $\log(V/L)_{i,t} - \log(V/L)_{i,t-1}$. The first difference form removes time trends which can introduce spurious correlation in level forms. On the other hand, year-to-year variations in productivity growth introduce substantial measurement error. In addition, it is by no means clear that current changes in regulation should immediately influence productivity growth, with no allowance for lags. Nevertheless, in columns (3), (4), and (5) the magnitude of the regulation effect is broadly consistent with column (2). However, in the rate of change version, the regulation effect is not significantly greater than zero.

Column (4) shows the impact of regulation in the rate of change version without state dummies.⁵⁸ The estimate, at -0.023 , falls broadly within the range of the other estimates. The evidence suggests though, though state dummies were crucial in the levels regressions, they are not necessary in the rate of change version; first differencing has swept out the importance of state dummies. Finally, column (5) reports a version in which the level of regulation is included as well as the

⁵⁶ For example, states such as California or Connecticut with high levels of regulation differ in many important respects from states such as Alabama or Texas which have low levels of regulation. To avoid conflating regulation with other characteristics of states we often include state dummies in the analyses.

As Grossman and Krueger (1995, p. 372) remark "As nations or regions experience greater prosperity their citizens demand that more attention be paid to the noneconomic aspects of their living conditions." The extent of regulation may therefore be associated with observed incomes. Regulations and related factors may also limit construction productivity in other countries. Lewis (2004) considers construction productivity in Japan (pp. 40 to 42) and in Europe (pp. 67 to 69).

⁵⁷ The F ratio with 47 and 1550 degrees of freedom is 75.3, far greater than the 95 percent significance level of approximately 1.36.

⁵⁸ In fact, an F test cannot reject the null hypothesis that all state dummies are equal to zero. The F value is 0.95, which is lower than the 95 percent F value of 1.36 with 47 and 1503 degrees of freedom.

growth of regulation. The data are not able to establish separate estimates of the impact of the growth and the level of regulation.

Table 9 The Effect of Regulation on Labor Productivity

Independent Variables	Dependent Variables				
	Log (V/L) _{i,t}		Log (V/L) _{i,t} - Log (V/L) _{i,t-1}		
	(1)	(2)	(3)	(4)	(5)
Log(Reg) _{i,t} t ratios	-0.0487 (-3.36)	-0.0276 (-2.41)			
Log(Reg) _{i,t} - Log(Reg) _{i,t-1} t ratios			-0.0259 (-1.31)	-0.0226 (-1.24)	-0.0274 (-1.38)
Reg _{i,t} t ratios					-1.0296 (-2.16)
State dummies	Yes	Yes	Yes	No	Yes
Time dummies	No	Yes	Yes	Yes	Yes
Time trend	Yes	No	No	No	No
Observations	1632	1632	1584	1584	1584
R ²	0.66	0.80	0.52	0.50	0.52
Standard error of estimate	0.11	0.09	0.03	0.03	0.03

Overall, the various estimates fall into a relatively narrow range of -0.023 to -0.049. We select the value $\hat{\beta} = -0.03$, close to the mean value of the various available estimates, as our primary measure of the effect of regulation on productivity growth.⁵⁹

Once our main estimate of $\hat{\beta}$, -0.03, has been determined, how do we use this parameter to measure the impact of regulation upon productivity growth in construction? Equation (4) can be rewritten in first difference form as:

$$\log(V/L)_{i,t} - \log(V/L)_{i,t-1} = \hat{\beta} (\log(\text{Reg})_{i,t} - \log(\text{Reg})_{i,t-1}) \quad (4b)$$

⁵⁹ An elasticity of -0.03 implies that a 100 percent increase in regulation reduces productivity by 3 percent. In 2010 *Reg* was 0.0007698 in Alabama and 0.0338765 in Maine. The index of regulation therefore doubles at least five times between the lowest and highest regulation states, which implies a productivity decline of 15 percent.

in which the rate of growth of regulation, since $\hat{\beta}$ is negative, reduces the rate of growth of labor productivity.

Consider that, in the absence of any year-to-year increase in regulation, observed $\log(V/L)_{i,t}$ would be higher in equation (4b). Specifically,

$$\log(V^*/L)_{i,t} = \log(V/L)_{i,t} + 0.03(\log(Reg)_{i,t} - \log(Reg)_{i,t-1}) \quad (4c)$$

where the new $V, V_{i,t}^*$, is the amount of output that would have occurred in the absence of any regulatory increase.

The new $(V^*/L)_{i,t}$ can be calculated from (4c) as⁶⁰

$$(V^*/L)_{i,t} = \exp[\log(V/L)_{i,t} + 0.03(\log(Reg)_{i,t} - \log(Reg)_{i,t-1})] \quad (4d)$$

Since $\exp[x + y] = \exp[x] * \exp[y]$,

expression (4d) is equal to:

$$(V^*/L)_{i,t} = (V/L)_{i,t} * \exp[0.03(\log(Reg)_{i,t} - \log(Reg)_{i,t-1})]$$

in which the second term expresses the multiplicative amount by which $(V/L)_{i,t}$ is increased due to the absence of any regulatory increase. Since $L_{i,t}$ is assumed to be unchanged, $\exp[(0.03(\log(Reg)_{i,t} - \log(Reg)_{i,t-1}))]$ at the same time also expresses the multiplicative increase in $V_{i,t}$.

By cumulating the new V^* values across the 48 states in each year, we can determine $\sum_1^{48} V^*$. Similarly, by cumulating the existing V_i values for each state we can determine $\sum_1^{48} V$. Then:

$$(\sum_1^{48} V^* / \sum_1^{48} V) - 1.0 \quad (5)$$

determines the percentage loss in construction output which occurs each year, at the aggregate level, because of increases in regulation. These calculations are carried out for each year, so equation (5) provides information on both the annual loss to construction productivity, and the time path of losses over time.

However, it is not necessary to assume, as in equation (4b), that regulation affects productivity only through a linear in logarithms (percentage rate change) relationship. For example, in Wyoming regulation grew at a very rapid rate, but started out at an extremely low level. We therefore next examine a more general model in which the same percentage increase in regulation affects productivity growth more severely in high regulation states.

⁶⁰ We take the exponent of both sides of equation (4c). $\exp[\log(V^*/L)_{i,t}] = (V^*/L)_{i,t}$.

As in standard in growth accounting, then, the same percentage increase in regulation may hold back productivity more strongly when the share of regulation is high. Specifically

$$\log(V/L)_{i,t} - \log(V/L)_{i,t-1} = \alpha_{REG}(\log(Reg)_{i,t} - \log(Reg)_{i,t-1}) \quad (4e)$$

(4e) allows increases in regulation to have a greater impact when the level of regulation is higher.⁶¹

We do not know α_{REG} , regulatory costs as a share of output. However, we do have information on land use regulation as a proportion of overall appellate cases. As a first approximation, we assume that the regulatory share of total costs is a multiple of the share of regulatory cases in total cases. For example:

$$\alpha_{REG} = \beta m \alpha_{CASES}$$

where α_{CASES} is the proportion of cases which involves land use, and m is a multiple which converts the share of legal cases into regulatory costs as a share of production costs. There may not be a one to one correspondence between α_{REG} , the share of cases, and the share of costs accounted for by regulation; it is quite plausible that x proportion of cases may consistently be associated with $2x$ proportion of costs.

Then:

$$\log(V/L)_{i,t} - \log(V/L)_{i,t-1} = \hat{\beta} m \alpha_{CASES}(\log(Reg)_{i,t} - \log(Reg)_{i,t-1}) \quad (4f)$$

In the context of expression (4f) we not need to know the value of β but only the joint product βm . Equation (4d) then becomes:

$$(V^*/L)_{i,t} = \exp[\log(V/L)_{i,t} + \beta m \alpha_{CASES}(\log(Reg)_{i,t} - \log(Reg)_{i,t-1})]$$

and all we need to determine the output lost due to increases in regulation is an estimate of the joint product βm which can be obtained from a regression based on equation (4f).⁶²

In principle, it is also possible to assume that the relationship between the share of costs and the share of legal cases contains a constant term, so that $\alpha_{REG} = a + \beta m \alpha_{CASES}$. However, our empirical analysis not able to obtain separate estimates of α significantly different from zero when we explore such possibilities.⁶³

⁶¹ In the empirical analysis, the share of regulation is measured by $\alpha_{REG,i,t-1}$, the share of regulation observed in the previous year. This form is adopted to reduce collinearity between α_{REG} and $\log(Reg)_{i,t} - \log(Reg)_{i,t-1}$.

⁶² In this version, the growth of regulatory limitations reduces productivity growth through increase in α_{CASES} as well as through the direct growth of $\log(Reg)_{i,t} - \log(Reg)_{i,t-1}$.

⁶³ If the share of regulation in total costs, α_{REG} , is equal to $a + \beta m(\text{share of cases})$ then the share weighted effect of increases in regulation $\alpha_{REG}(\log(Reg)_{i,t} - \log(Reg)_{i,t-1})$ equals $a(\log(Reg)_{i,t} - \log(Reg)_{i,t-1}) + \beta m \alpha_{CASES}(\log(Reg)_{i,t} - \log(Reg)_{i,t-1})$. However, column 3 of Table 10 shows that we cannot obtain separate estimates of α and β .

Empirical results from equation (5), based on the coefficients in Table 9, indicate that observed increases in regulation have consistently had a slight negative effect on productivity growth in construction. However, there is no evidence that regulation has had a major impact, such as would be required to explain the major productivity declines observed in Table 1. Over the entire 1977 to 2010 period regulation reduced productivity growth by 0.054 percent per year, which, rounded off, implies an annual productivity loss of only 0.1 percent per year. The negative impact of regulation declined somewhat over time. From 1977 to 1987 the annual loss was 0.094 percent per year. From 1987 to 1997 the loss was 0.039 percent per year. From 1997 to 2010, the negative regulation effect was 0.036 percent per year.

Table 10 considers the alternative specification described in equation (4e) in which the effect of the growth of regulation also depends on the implied share of regulation. The third column reports estimates with the rate of change of regulation and the rate of change weighted by the regulation share both included as separate independent variables. The data clearly prefer the share weighted version, although columns (1) and (2) indicate that there is not much difference in the explanatory power provided by each variant. When the share weighted version is used to estimate the effect of regulation on productivity growth, the estimated long-term effect is slightly greater, at 0.068 percent per year instead of 0.054 percent, but this still rounds off to a long-term effect of 0.1 percent per year. In addition, the share weighted model suggests that regulation has approximately the same impact over time, whereas the constant return model implies that the productivity impact of regulation declines steadily over time. From this point of view, as well, the share weighted model seems more plausible.⁶⁴

⁶⁴ F tests again reject state dummies, but fail to reject time dummies in Table 10.

Table 10 Estimates of the Effect of Regulation on Productivity Growth when the Impact of the Growth of Regulation is Weighted by the Regulation Share.

Independent Variables	Dependent Variables		
	Log (V/L) _{i,t} - Log (V/L) _{i,t-1}		
	(1)	(2)	(3)
Log(Reg) _{i,t} - Log(Reg) _{i,t-1}	-0.0226		0.006
t ratios	(-1.24)		(0.25)
(Log(Reg) _{i,t} - Log(Reg) _{i,t-1})*Reg _{i,t-1}		-7.4884	-8.2352
t ratios		(-2.18)	(-1.8)
State dummies	No	No	No
Time dummies	Yes	Yes	Yes
Time trend	No	No	No
Observations	1584	1584	1584
R ²	0.50	0.50	0.50
Standard error of estimate	0.03	0.03	0.03

Source: Regressions based on equation (4e).

Since the average value of the share of cases involving land use is approximately 0.005 in the total sample, and since the preferred coefficient for $\alpha_{CASES}(\log(Reg)_{i,t} - \log(Reg)_{i,t-1})$, in column (2) of Table 10, is -7.4884, the implied factor share for regulation is -7.4884 x 0.005 in the average observation. This represents a negative effect equivalent to 3.7 percent of total costs in construction.⁶⁵ Since the share of cases increases over time, the implied cost share of regulation is greater in more recent years.⁶⁶

⁶⁵ Of course, since output is defined as value added throughout this subsection, the estimated share is 3.7 percent of value added costs.

⁶⁶ In addition to the measures of regulation considered in Section VA, broader environmental restrictions, which are arguably less likely to invoke the specific term "land use", may also limit productivity in construction. Smith, von Haefen, and Zhu (1999) show that Federal environmental restrictions affect the productivity of federal highways, but have no impact on state and local highways not covered by these restrictions. A separate part of their work asked state Department of Transportation officials to estimate how much higher costs were for highway construction covered by federal restrictions. Mean estimates were in the 8 to 10 percent range.

In summary, we conclude that regulation has had a significant negative effect on productivity growth in construction, but that regulation can explain only a small part of the productivity declines described in Section I.⁶⁷

Some of the positive effects of regulation no doubt do not appear in the productivity numbers. Regulation is likely to improve compliance with building codes, such as the security of the electrical system or protection of houses from hurricanes or water damage. These upgrades provide consumers with protection, such as freedom from electrical fires. However, such improvements are not likely to appear in construction output. Even when hedonic methods of output are in use, such improvements are too specialized to appear in the standard measures of output. In addition, measures of the effect of regulation on productivity growth in construction do not reflect potential benefits which residents of the existing housing stock may obtain if regulation preserves amenities which are important to them. Potential negative effects of regulation on construction productivity are therefore only part of a much broader picture.

Section VA measures construction productivity in each state by dividing Bureau of Economic Analysis estimates of gross product originating in each state by BEA estimate of the number of construction employees in the state. The number of employees includes partners and proprietors, but not unpaid family workers; however, unpaid family workers are uncommon in construction. We attempted to gather information on average weekly hours in construction in each state from the American Community Survey and the Census of Population. However, average weekly hours obtained from the American Community Survey were highly variable in small states, such as South Dakota or Wyoming. Therefore, we did not proceed further with attempts to measure average weekly hours in each state.⁶⁸

In their article, Ganong and Shoag have shown that their proposed index of land use regulation is a primary driver of many of the observed patterns of urban and state economic development. This

⁶⁷ According to the specification adopted in equation (4b), productivity is more adversely affected in individual states where regulation increases more rapidly. For example, regulation reduced productivity by 0.08 percent per year in California and by 0.11 percent per year in Connecticut. Regulation decreases productivity by 0.10 percent or more per year in 10 of the 48 states.

It may be possible to allow for lags in the effect of regulation. However, since the Ganong-Shoag measure is cumulative, considerable lags are already built into the index. We briefly experimented with long-term differences, as suggested in the Griliches and Hausman (1986) analysis of panel data. Though long-term differences sometimes provide a hint that the effects of regulation are substantially stronger, on balance we have not found any consistent evidence of a greater impact.

Real estate specialists apparently use the measure of state-average impact fees as one measure of the impact of regulation. In 2010, Mullen (2010) reported state-average impact fees for 33 of the 48 states considered here. The Duncan data report separate measures of impact fees for single family housing, multiple family housing, retail, office, and industrial construction. The correlation between single-family impact fees and the 2010 Ganong-Shoag index of regulation is 0.36. The correlation with multiple family impact fees is 0.31. The correlation with the (unweighted) average impact fee across all five types of construction is 0.28.

⁶⁸ Regrettably, it does not seem feasible to measure either gross output prices or materials prices for the entire construction industry in each state.

paper shows that the Ganong and Shoag index can also help to explain observed patterns of productivity growth in the construction industry. Such results provide further support for the relevance and importance of the Ganong-Shoag index of regulation.

VB. Correcting for the Number of Undocumented Immigrants.⁶⁹

When we first considered developing measures of productivity growth in construction, commentators frequently emphasized that many undocumented immigrants worked off the books, so it would be extremely difficult to establish accurate measures of labor input. Because of the potential importance of undocumented immigrants in construction, it is necessary to address this issue. Since the prevalence of undocumented immigrants varies sharply from state to state, Section VB evaluates the role of undocumented immigrants from state data, using Pew Hispanic Center estimates of the number of undocumented immigrants in each state. However, we cannot use the standard Bureau of Economic Analysis measures of construction output and labor input in each state to evaluate the presence of undocumented immigrants. BEA data on state incomes are prepared from the income side, compiled from information on labor inputs, compensation, and other factor income in each state. If the reported data on employment and earnings omit undocumented immigrants, BEA estimates of output and labor input will both be understated. Subsection VB therefore instead examines whether undocumented immigrants are included in the underlying BLS data on employment and earnings in construction.

Undocumented immigrants are particularly important in the construction industry. Passel (2006) showed that undocumented immigrants are far more likely to work in construction rather than in most other industries. Although undocumented immigrants represented 4.9 percent of the total work force in 2005, they accounted for 12 percent of workers in the construction and extractive industries.⁷⁰

Passel believes that counts of population, such as the Census of Population and Housing and the American Community Survey, generally collect information on population fairly accurately, presumably especially when such counts are bolstered by special efforts to count hard to measure groups.⁷¹ However, it is uncertain whether such optimism carries over to establishment surveys, such as the Census of Construction or the Current Employment Statistics, where undocumented workers may be more likely to be working off establishment books.

⁶⁹ We are indebted to participants in the 2013 Census-BLS Research Workshop for suggesting that we examine how the presence of undocumented immigrants affects observed productivity measures.

⁷⁰ Passel (2006) provides estimates of the proportion of workers in specific occupations who were undocumented immigrants. Many construction occupations have very high proportions of undocumented workers. Examples are insulation workers (36%), roofers (29%), drywall installers (28%), helpers in construction trades (27%), construction laborers (25%), brick and stonemasons (25%), painters (construction and maintenance) (22%), cement masons (21%), and carpet, floor, and tile installers (20%).

⁷¹ Passel explains that in his analysis he increases estimates of undocumented employment obtained from U.S. population surveys by approximately 10 to 15 percent based upon data from the Mexican Census and based upon questionnaires which ask Mexicans in the United States whether they have responded to the U.S. Census (Pew Research Center, 2013).

To address whether establishment data cover undocumented immigrants accurately, we compare employment count trends in population surveys and in establishment data. Part of the analysis is limited to large states because information on the presence of undocumented immigrants and on construction employment is more reliable in large states where samples, drawn from Current Population Survey or the American Community Survey, are much larger.⁷²

Assume that the annual growth rate of employment in construction in state i observed in the population data is $g_{POP,i}$. Similarly, the annual growth rate of employment observed in establishment data is $g_{EST,i}$. The number of undocumented immigrants as a proportion of the population in state i in year t , as obtained from Passel's estimates, is $UND/POP_{i,t}$.

Given this terminology, what sort of employment trends do we expect if the proportion of undocumented immigrants in the population of a state, $UND/POP_{i,t}$, increases. What is relevant for the labor market is not the rate of growth of $UND/POP_{i,t}$, which could be very high when the undocumented immigrant proportion of population increases a miniscule amount, perhaps from 0.0001 to 0.0002. What matters instead is how large the flow of undocumented immigrants is as a proportion of the population. We choose to measure this effect by

$$\left[UND/POP_{i,2} - UND/POP_{i,1}\right]/n \quad (6)$$

that is the undocumented immigrant to population ratio in state i in year 2, $UND/POP_{i,2}$, minus this ratio in year 1, all divided by n , the number of years between years 1 and 2. Expression (6) tells us the annual amount by which the undocumented immigrant to population ratio is increasing in each state. In some decades in certain states, such as California, Texas, Florida, Arizona, and Nevada, the undocumented immigrant to population ratio surges rapidly. In other areas, the increase in undocumented immigrants is often negligible.

We estimate the impact of the flow of undocumented immigrants described in equation (6) on the measurement error in employment through a regression of the form:

$$g_{EST,i} = a + bg_{POP,i} + c \left[\left[UND/POP_{i,2} - UND/POP_{i,1}\right]/n \right] \quad (6b)$$

Equation (6b) first adjusts the growth of construction employment in the establishment data for the corresponding growth of employment observed in the population data. Then, after correcting for overall trends, equation (6b) examines whether unusual increases in the presence of undocumented immigrants especially depress observed increases in establishment employment. We emphasize that equation (6b) refers only to the growth of construction employment in establishment data relative to population data.⁷³ What sort of increase in establishment employment might we expect if there is an

⁷² Table A-3 of Passel and Cohn (2011), presents estimates of the number of undocumented immigrants in each state in 1990, 2000, 2005, 2007, and 2010. Passel and Woodrow (1984) provides an estimate of the number of undocumented immigrants in each state in 1980.

⁷³ As a base line estimate, Passel believes that 10 to 15 percent of undocumented immigrants do not show up in population counts. In future work, we hope to investigate how the presence of immigrants affects measured

increase of one percent in the ratio of undocumented immigrants to population, $[[UND/POP_{i,2} - UND/POP_{i,1}]/n]$? If undocumented immigrants systematically work off the books and do not appear in establishment data, then the presence of undocumented immigrants will distort the usual relationship between $g_{EST,i}$ and $g_{POP,i}$ and the coefficient \hat{c} will be negative. On the other hand, if undocumented immigrants are not systematically underreported in establishment data (again relative to the population data), \hat{c} will be 0. If the establishment data measure undocumented immigrants more fully than the population data \hat{c} will be positive.

We estimate equation (6b) for the decades 1980-1990, 1990-2000, and 2000-2010, covering 144 observations in the 48 states.⁷⁴ Somewhat to our surprise, the coefficient c is always positive and significant.⁷⁵ There is no evidence that employment in construction establishments is suppressed (relative to the population data) when undocumented immigrants become much more plentiful. In fact, employment in construction establishments tends to increase even more than employment from the well-regarded population surveys.⁷⁶

Our empirical results for construction suggest that employment data from administrative records do not omit more undocumented immigrants than Census population data do. In his April 2013 interview Passel estimated that population records miss 10 to 15 percent of undocumented immigrants. Of course, construction employs a greater proportion of undocumented immigrants than most other industries (Passel, 2006), so the numbers of immigrants omitted in construction will be greater for this

productivity in different portions of the construction industry, such as housing, heavy construction, and contractors, using Census micro data on construction establishments.

One potential limitation is that measures of industry employment are self-reported in surveys of population, and may consequently contain too much noise to be useful.

⁷⁴ Different sections of this paper examine productivity growth in construction in different time periods. Section IIA examines productivity growth in single-family and multiple family residential construction from 1987 to 2011, and highway construction from 2002 to 2011. Section IV considers labor shifts between 1987 and 2007. Section VA examines productivity growth in individual states between 1977 and 2010. All of these sections use labor inputs obtained from administrative data, mostly from CES but also from the Census of Population. Here in Section VB, we choose to examine employment trends between the Census of Population years of 1980 and 2010, a broad period which covers most of the range of relevant years between 1977 and 2011.

⁷⁵ The regression result for all 48 states is

$$g_{EST,i,t} = -0.00564 + 1.1026g_{POP,i,t} + 3.32 \left\{ \frac{[UND/POP_{i,2} - UND/POP_{i,1}]}{n} \right\} \quad \begin{array}{l} 48 \text{ states, 144 observations} \\ \bar{r}^2 = 0.84 \quad (-4.11) \quad (25.91) \quad (2.62) \quad \text{t ratios} \end{array}$$

For the 40 states with the best data:

$$g_{EST,i,t} = -0.0071 + 1.0937g_{POP,i,t} + 4.14 \left\{ \frac{[UND/POP_{i,2} - UND/POP_{i,1}]}{n} \right\} \quad \begin{array}{l} 40 \text{ states, 120 observations} \\ \bar{r}^2 = 0.85 \quad (-4.67) \quad (24.05) \quad (3.18) \quad \text{t ratios} \end{array}$$

⁷⁶ One of our readers has suggested that we examine the dependent variable $g_{EST,i} - g_{POP,i}$ instead of the specification adopted in equation (6b). We had considered this alternative, but decided against it because it assumes that $\hat{\beta} = 1.0$. Results from this alternative form indicate that $\hat{c} = 4.06$ with a t ratio of 3.24, not very different from $\hat{c} = 3.32$ with a t ratio of 2.62 in footnote 75.

reason.⁷⁷ Nevertheless, many people we have spoken with believe that the proportion of uncounted undocumented immigrants is far greater than the numbers mentioned above imply. How can so many people believe that uncounted workers are so much more prevalent in construction than such estimates indicate?

We believe that one potential reason for systematic misperception is that, according to industry sources, undocumented immigrants are concentrated in housing construction, especially among the subcontractors who provide services to home builders. Within the home builder work force, immigrants are especially prevalent in foundation and framing work but also perform other tasks. In addition, immigrant workers are more concentrated in certain cities or areas than in much of the rest of the country.

We suspect that observers tend to notice the large immigrant presence in the highly visible housing sector in a particular city, such as Washington, D.C., and thereby overstate the immigrant role in overall construction throughout the United States. On the other hand, it is also logically possible that Passel's studies, though generally regarded as the best and most careful work on immigrants who do not appear in official statistics, may nevertheless still substantially underestimate the role of off-the-books immigrant workers.

To prepare ballpark estimates of how much the omission of some undocumented immigrants affects measured productivity growth in construction, consider the absolute number of undocumented immigrants and the proportion of the labor force they represent from Passel and Cohn (2011). They report:

Table 11 Numbers of Undocumented Immigrants and Their Role in the Labor Force

⁷⁷ If immigrants are 2.45 times as likely to work in construction, as argued below, their influence in construction would be equivalent to 20 percent intensity of undocumented workers in the total labor force (Passel, 2006).

Year	Undocumented Immigrant Estimated Labor Force (millions)	Undocumented Immigrant Share of Labor Force
2000	5.5	3.8%
2001	6.3	4.3%
2002	6.4	4.4%
2003	6.5	4.4%
2004	6.8	4.6%
2005	7.4	5.0%
2006	7.8	5.2%
2007	8.4	5.5%
2008	8.2	5.3%
2009	7.8	5.1%
2010	8.0	5.2%

Source: Passel and Cohn (2011).

We estimate 2011 on the basis of further data. The next step is to bring in further data for years prior to 2000. First, we obtain data on the population of undocumented immigrants from Passel (2005).

Relevant data are:

Period	Undocumented Immigrants (millions)	US Population (Beginning of month)	Undocumented Immigrant Population Share
Jun-86	4.0	240	
Jun-89	2.5	247	1.0%
Oct-92	3.9	258	1.5%
Oct-96	5.0	270	1.8%
Apr-00	8.4	281	3.0%

We do not estimate the presence of undocumented immigrants in 1987 by interpolating between the 1986 and 1989 data because the apparent decrease in the number of undocumented immigrants from 1986 to 1989 represented a legalization of prior undocumented immigrants rather than any real change in immigration flows. Instead we estimate the immigrant share of total population in 1987 as 0.0071, obtained by extending the 1989 to 1992 trend in the immigrant share of population backwards to 1987.⁷⁸

Once we have the undocumented immigrant population shares from 1987 to 2000, we convert the immigrant population shares to labor force shares by assuming that the labor force share/population share multiplier observed in 2000 also holds true for earlier years. In 2000 the immigrant share of population was 0.02985, whereas the labor force share was 0.038, leading to a ratio

⁷⁸ The undocumented immigrant share of total population increases from 0.01014 in 06-89 to 0.01515 in 10-92, an increase of 0.00501 in 3 1/3 years. This represents an increase of 0.0015 per year or 0.003 over two years. Subtracting 0.003 from 0.01014 leads to a 1987 estimate of 0.0071.

of 1.2731 ($0.038/0.02985 = 1.2731$).⁷⁹ Using the conversion ratio of 1.2731 provides the following labor force shares:

Year	Undocumented Immigrant Population Share	Conversion Ratio	Undocumented Immigrant Share of Labor Force
1987	0.71%	1.27310	0.91%
1992	1.51%	1.27310	1.93%
1996	1.85%	1.27310	2.35%
2000	2.98%	1.27310	3.80%

The 1997 version of the immigrant labor force share, which falls between 1996 and 2000, is interpolated as 0.0272.

We now have estimates of the undocumented immigrant share of the labor force for each year of interest. The next task is to determine what proportion of this labor force works in construction each year. We assume a linearity in that the immigrant share of the work force in construction is a linear function of the percentage of undocumented immigrants in the total work force. For example, Passel (2005) notes that 12 percent of all construction workers in 2005 were undocumented immigrants. In 2005, undocumented immigrants represented 4.9 percent of the work force. We assume that each one percent of the work force, who are undocumented immigrants, leads to $12/4.9$ or 2.45 percent representation of undocumented immigrants in the construction work force.⁸⁰ With this conversion factor, we can convert our existing measures of the proportion of immigrants in the work force into their equivalent representation in the construction work force. Carrying out this conversion:

⁷⁹ Passel and Cohn (2011) show that undocumented immigrants were 3.8 percent of the labor force in 2000. Passel (2006) shows undocumented immigrants were 8.4 million in April 2000. The Census Bureau population clock website shows that the United States population on April 1, 2000 was 281.4 million, so undocumented immigrants accounted for $8.4/281.4 = 0.02985$ of the 2000 population.

Dividing 0.038 by 0.02985, the population has to be multiplied by 1.2731 to obtain labor force estimates. Of course, the labor force share is greater than the population share because most undocumented immigrants are of working age. In addition, children born in the United States are legal residents.

⁸⁰ The assumption of linearity means that each one percent increase of undocumented immigrants in the labor force is associated with a given proportion increase of undocumented in construction. For example, if 1.0 percent undocumented immigrants in the labor force is associated with 2.5 percent of workers in construction, then 2.0 percent of undocumented immigrants in the labor force will be associated with 5.0 percent of undocumented immigrants in the construction work force, and a 3.0 percent overall rate will be associated with 7.5 percent of the construction work force. At present, we do not have sufficient empirical evidence to test the validity of this assumption. However, if the proportion of construction jobs accessible to unskilled workers is limited, as seems reasonable, then increased proportions of undocumented immigrants may well be associated with slower increases in the role of undocumented immigrants in construction. If so, the estimates of the effect of uncounted undocumented immigrants on productivity growth developed later in Section VB will be overstated.

Year	Undocumented Immigrant Share of Labor Force	Labor Force to Construction Multiplier	Undocumented Immigrant Share of Construction Work Force
1987	0.91%	2.449	2.2%
1992	1.93%	2.449	4.7%
1997	2.72%	2.449	6.7%
2000	3.80%	2.449	9.3%
2001	4.30%	2.449	10.5%
2002	4.40%	2.449	10.8%
2003	4.40%	2.449	10.8%
2004	4.60%	2.449	11.3%
2005	5.00%	2.449	12.2%
2006	5.20%	2.449	12.7%
2007	5.50%	2.449	13.5%
2008	5.30%	2.449	13.0%
2009	5.10%	2.449	12.5%
2010	5.20%	2.449	12.7%
2011	5.25%	2.449	12.8%

We now have estimates of the immigrant work force employed in construction in each of these years.⁸¹ When we combine the estimates of the immigrant share of construction workers with information on the total number of hours worked in construction from 1987 to 2011, the data suggest that immigrant hours grew at an 8.26 percent annual rate over this period, while native hours increased by 0.15 percent per year. However, even by 2011, immigrants still remained a fairly small proportion of overall labor input.

Our current estimates show that labor hours in construction grew at a 0.63 percent annual rate from 1987 to 2011. If we follow Passel in estimating that 15 percent of undocumented immigrants are off the books, beyond our data, then there is a greater increase in immigrant labor than our data show, but the unmeasured increment would only be sufficient to increase our labor input to 0.70 percent per year, implying a 0.07 percent decrease in productivity growth. If 30 percent of undocumented immigrants are off the books, this would increase true labor input growth to 0.76 percent per year, implying a 0.13 percent decline in labor productivity growth. The implied effects on productivity growth are not immense; the undocumented immigrant share of the work force still remains sufficiently small

⁸¹ Of course, it would be possible to estimate the number of undocumented immigrants working in construction in each year directly from the relevant annual data provided by CPS or the American Community Survey, along the lines of the detailed methodology introduced by Passel. Such work would represent an improvement, but would move us further away from our emphasis on productivity. We caution that the estimates developed in Section VB provide only a ballpark impression of the orders of magnitude involved.

As mentioned in footnote 71, we hope to determine how undocumented immigration affects measured productivity in different industries in construction, using Passel's data on undocumented immigrants in each state in each decade and Census micro data for construction.

that an understatement of the growth of undocumented immigrant labor does not greatly alter our understanding of productivity growth in total construction.⁸²

On the other hand, the immigrant influence has clearly been much more substantial in certain portions of construction, such as in home building and especially among subcontractors for home building. However, we do not attempt to obtain empirical estimates of the bias thereby introduced because there is so little solid information on the immigrant share of the work force in particular portions of construction and, especially, on how the immigrant share changes over the business cycle.⁸³

VI. Conclusions

Measurement of construction productivity has been a difficult task for many years. As the list of references in the present paper indicates, not much progress has been made on this topic since the 1980s. Nevertheless, we are able to report some steps forward. First, reasonable deflators already exist for industries representing almost one quarter of the value of construction work. Second, the PPI has produced additional deflators which, after the 2012 Census of Construction becomes available, can be used to measure productivity growth in many further areas of construction.

Measures of productivity growth in residential construction and in the construction of highways, streets, and bridges already provide some useful information. These series show little evidence of a sustained negative trend in construction productivity. It is true that productivity growth in residential construction fell sharply after the housing collapse of 2006-2008. Nevertheless, prior to the boom there is little evidence that long-term productivity growth rates were negative in residential construction. In addition, once productivity growth is corrected for cyclical fluctuations, the evidence suggests that the observed productivity trends will again be positive once housing starts revert to more normal levels. Productivity growth in highways, streets, and bridges is positive, though this probably reflects countercyclical policies which disproportionately stimulated highway construction. Overall, evidence from these three industries shows no sign of a consistent or sustained decline in productivity.

In contrast, the new PPIs increase more quickly than the old unreliable deflators within several areas of construction. Such evidence suggests that over history output growth in construction was probably at least somewhat overstated. This sort of evidence makes the view that productivity deteriorated over the long term more tenable.

⁸² One of our readers has expressed concern that our methodology does not allow for changes in the construction share of total employment. However, the construction share of nonfarm employment was 0.049 in 1980, 0.048 in 1990, 0.051 in 2000, and 0.042 in 2010. These changes are not sufficient to change the implied trends of immigrant employment in construction very much. In addition, the low 2010 proportion, no doubt associated with the 2007 crash in construction, implies that even fewer immigrants than we have estimated were employed in construction in recent years.

⁸³ As mentioned in footnote 19 above, the share of undocumented immigrants in housing or in construction may increase substantially when the demand for construction is high. Unfortunately, there is little reliable information on how the immigrant share of employment varies with the business cycle.

Labor shifts from high to low productivity industries contributed 0.46 percent per year to the decline in productivity observed from 1968 to 1978 (Allen, 1985). We found that hours shifts reduced productivity growth by 0.26 percent per year between 1987 and 2007, an amount smaller than found by Allen, but nonetheless a substantial amount. Labor shifts now represent shifts from heavy construction to contractors, whereas Allen emphasized shifts towards housing. Increases in regulation have a significant negative effect on observed productivity growth in construction, within state data which allow for differences in regulatory regimes. The implied factor share cost of regulation is estimated to be 3.7 percent of total costs for a typical observation included in the data examined. Nevertheless, the implied impact on aggregate productivity growth in construction is slight, perhaps -0.1 percent per year.

Overall, we have so far found only partial explanations for declining levels of productivity in construction. Labor shifts are still important in our analysis. Future work will expand the number of industries for which we are able to prepare useful measures from three to eleven or more and will develop estimates of multifactor productivity growth within each of these industries.

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Appendix A. Development of Productivity Measures for Individual Industries.

Appendix A describes the procedures through which labor productivity growth is calculated for the various industries included in construction. As Section II indicates, the industries examined are single family residential construction, multiple family residential construction, and the construction of highways, streets, and bridges. However, similar methods are also used to develop corresponding measures of shipments and of labor inputs in all the other construction industries.

Appendix A contains a detailed discussion of every data element and every data source. The text reports the specific economic series from which each data element is obtained, and also describes the full and exact procedures used to prepare and combine various data items. For example, Appendix A lists exactly which data source is used to interpolate each measure between Census years, and also provides the exact formula used to determine the specific values of the series in each of the intervening years.

In turn, the discussion considers measures of output, output deflators, employees and employee hours, and partner and proprietor labor inputs.

Measures of Output.

Output of individual industries.

We start out with measures of output in each individual industry. We begin with the 2007 Census of Construction, which, at the time this text was written was the most recent version of the Census. Table A-1 below reports information on the value of production in each of our industries in 2007; data are from Table ECO723SG01 of the 2007 Census of Construction and from the 2007 Non-Employer Statistics. The first column of data shows the value of output (value of business done) in the industry for establishments which report a labor compensation payroll. The second column of data reports the value of output (again, the value of business done) for those establishments without payroll, essentially those establishments with only self-employed workers. The third column of data in Table A-1 reports total output, the sum of output in each category.

Table A-1 Value of Business Done by Construction Industry, 2007, in millions of dollars.

Industry	Title	With Payroll	Without Payroll	Implied Total Value of Business
2361	Residential Building Construction	358562.4	50920.6	409483.0
236115	New Single Family Housing Construction (Except For-Sale Builders)	90006.2	12782.1	102788.2
236116	New Multifamily Housing Construction (Except For-Sale Builders)	34702.9	4928.3	39631.2
236117	New Housing For-Sale Builders	181371.2	25757.1	207128.4
236118	Residential Remodelers	52482.1	7453.2	59935.2
237310	Highways, Streets, and Bridge Construction	106598.3	472.7	107071.0

Source: 2007 Census of Construction, Table ECO723SG01, Construction: General Summary: Detailed Statistics for Establishments: 2007; 2007 Non-Employer Statistics.

For residential construction, we have information on the value of business in the second category, for establishments without payroll, for all of residential construction, but no detail is available for each of the component industries. We therefore assume that the percentage increase in output observed within the broader category in general ($50920.6/358562.4 = 0.142013$) is also directly applicable to each individual industry. Some of the data reported in the second column of data are therefore estimates, marked by italicization. For highways, streets, and bridges actual information on output in establishments without payroll is directly available.

Primary vs. secondary products.

Like many other measures of industry production, the Census of Construction is collected from data on establishments. Some of the establishments assigned to a particular industry typically produce other products, characteristic of other industries, as well. Therefore, total production within an industry contains both products primary to that industry and secondary products, those typically produced by other industries. Within each industry, we distinguish between four categories, products primary to that industry, secondary products within construction for which we have adequate deflators (essentially single family housing, multiple family housing, and highways, streets, and bridges), secondary products in construction without adequate deflators (all other construction products), and secondary products outside construction. In 2007, the percentage of output falling within each of these categories was:

Title	Primary Construction	Secondary Construction with a good deflator	Secondary Construction without a good deflator	Outside of Construction
New Single Family Housing, including For-Sale Builders	88.5%	2.5%	8.4%	0.7%
New Multifamily Housing, including For-Sale Builders	76.9%	3.1%	19.6%	0.4%
Highway, Street, and Bridges	84.4%	0.0%	13.3%	2.2%

These data show that, in our three industries, most of output, from 76.9 to 88.5 percent, represents primary production in 2007. The two industries in housing each pick up a few percentage points of additional coverage from other industries with adequate deflators. The third column of data shows the proportion of output in the most troublesome category, other construction industries without reliable deflators. In these instances, we use the primary deflator to deflate these other types of construction output. The fourth column of data shows the proportion of output which falls outside the construction sector; acceptable deflators are generally available for most industries outside construction.

The third column of data, secondary construction products without deflators, therefore presents the most serious problems. This represents 8.4 percent of output in single family homes, 19.6 percent in multiple family homes, and 13.3 percent in highways, streets, and bridges. Such proportions of un-priced secondary products are not unusual in determining output growth in many industries outside manufacturing. In these circumstances, we use the price index for primary products to price those sectors without an adequate specific deflator; the Division of Industry Productivity Studies of BLS has used closely similar procedures to price secondary output in many other industries.

Table A-2 illustrates the methods used to calculate secondary product prices outside construction. This table indicates the importance of secondary products outside construction for each relevant industry in 2007. Note that the proportion of secondary products is calculated from data for establishments with payroll, only, as reported in the first column of data in Table A-1. Table A-2 shows that the proportion of secondary products obtained from outside construction is quite minor for each industry considered.

Table A-2 Value of Business Done, Value of Construction Receipts, and Value of Other Business Receipts, by Industry, 2007 (in millions of dollars).

NAICS	Title	Value of Business Done (1)	Value of Construction Work (2)	Value of Other Business Receipts (3)	Percentage of Work Outside of Construction (4)=(3)/(1)
236115	New Single Family Housing	90006.16	89282.708	723.452	0.8%
236116	New Multifamily Housing	34702.903	34559.434	143.47	0.4%
236117	New Housing For-sale Builders	181371.233	180056.841	1314.393	0.7%
237310	Highway, Street, and Bridges	106598.346	104256.162	2342.184	2.2%

Source: 2007 Census of Construction, Table ECO723SG01, Construction: General Summary: Detailed Statistics for Establishments: 2007

Nevertheless, these secondary products have to be priced by the appropriate deflator, which is different from the deflator primary to each industry. Table ECO72314 of the 2007 Census of Construction (Construction: Industry Series: Preliminary Value of Business Done for Establishments by Kind of Business Activity: 2007) provides detailed information on exactly what sort of secondary production is produced by the establishments classified within each industry. The composition of secondary products observed outside construction in 2007 is assumed also to hold true in every other Census year.⁸⁴

To give a specific example, in one particular industry specific secondary products external to construction include architectural services, engineering services, rental or lease of properties, and all other business activities secondary to construction activities. The all other business activities secondary to construction activities category is dropped, since it is difficult to determine what activities this category includes and how to price these activities. All the other secondary activities are used to establish a fixed weight price index, with weights based upon the observed 2007 expenditures. Each secondary product is assigned to an industry and then associated with the appropriate price index for that industry, typically obtained from the PPI.

We obtain information on how much output falls into each of our four categories from each Census of Construction. As explained above, once the price of secondary products in construction for which no adequate deflator exists has been estimated, from the primary price, we then have a price for

⁸⁴ Although the composition of non-construction products produced in 2007 is assumed to hold true in every other Census year, the actual weight of non-construction products in total output is permitted to vary with actual data for each Census year.

each of the four types of primary or secondary output.⁸⁵ We also have corresponding data on the value of output for each of the same four types of output. Once all this information on the prices and on the value of output is in hand, we have sufficient data to calculate a Tornqvist index of output which covers all primary or secondary production within each industry. This Tornqvist index is our measure of output in each industry.

Allocating the output of for-sale builders to single and multiple family construction.

In 2007 the Census of Construction reported separate data for NAICS industry 236115, single family residential construction, industry 236116 multiple family construction, and industry 236117, for-sale builders. In 2002, NAICS 236117 was called new housing operative builders, but the content of this industry was apparently quite similar to the industry boundaries observed in 2007. However, in the 1997 Census, and in prior years, NAICS 236117 did not exist, and its contents were instead included in NAICS 236115 or 236116. Table A-3 shows the relevant bridge table from the 2002 Economic Census.⁸⁶ On the basis of this bridge table, 98.00 percent of NAICS 236117 output is assigned to single family residential construction, and 2.00 percent of output is assigned to multiple family residential construction. As the bridge table also indicates, all of single family construction remains in that category, though the NAICS number changes, and all of multiple family construction also remains in that category.

Table A-3 Bridge Table Allocating NAICS 236117 to Its Single and Multiple Family Components.

2002 NAICS	1997 NAICS	Establishment Ratios	Value of Business Done Ratios	Payroll Ratios	Employees Ratios
236115	233210	100.00%	100.00%	100.00%	100.00%
236116	233220	100.00%	100.00%	100.00%	100.00%
236117	233210	98.27%	98.00%	96.97%	96.68%
236117	233220	1.73%	2.00%	3.03%	3.32%

Source: 2002 Economic Census, Table 1, Bridge Between 2002 NAICS and 1997 NAICS. Note that NAICS 236118, residential remodelers, was also allocated to NAICS 233210, single family construction and NAICS 233220, multiple family construction in 1997. However, we do not include residential remodelers in our single and multiple family measures to make sure that the output measures are aligned with the available price indices, which refer only to new construction. As is standard in the use of most bridge tables, residential remodelers are assumed to account for the same proportion of output in NAICS 233210 and NAICS 233220 in 1987-1996 as they were in 1997.

⁸⁵ As in the text above, the four categories of output considered are primary products, secondary products in construction where an adequate deflator exists, secondary products in construction with no adequate deflators, and secondary products outside construction.

⁸⁶ The specific reference is 2002 Economic Census, Bridge Between 2002 NAICS and 1997 NAICS for All Sectors. Operative builders are allocated to the single and multiple family categories, but the residential remodelers also included in the bridge table are not included in any of our measures.

Output Price Deflators.

Single family residential construction.

This portion of the discussion considers and presents the specific deflators used to deflate each of the output series described above. Each of the deflators considered is converted to an index value of 100.0 in the year 1987, to ensure that output is measured consistently across different types of construction. The most influential deflator used, which represents the largest volume of construction activity, is the deflator for single-family residential construction. This series has a long history, dating back to Musgrave (1969).

All information on the price index for single family residential construction is obtained from the Census Bureau web page on Construction Price Indexes. We select the series on the price index for houses under construction. The alternative index for new single family houses sold is inappropriate for our purposes because it includes the value of the lot and certain other costs outside the bounds of construction.

Among the various Census Bureau price series for houses under construction, we adopt the annual series on the Fisher price deflator. As the discussion of General Information on the Census Bureau web page indicates, the Fisher Ideal Index is appropriate to measure the value of today's homes being constructed in constant dollars. Specifically "This index can be used as a price deflator in determining the constant dollar value of today's output of houses under construction, which is included in the Gross Domestic Product."

The portion of the Census web page dealing with the Details of the Regression Models explains how the regression estimates correct for items such as square footage, the number of bedrooms or bathrooms, the presence or nature of a garage, and the characteristics of the heating and cooling system. House characteristics also include several geographic variables.

The Census web page provides specific values of the Fisher Ideal Index for single family residential construction in each year. Table A-4 reports the annual price index used for every year between 1987 and 2012. This is the specific series used to deflate single family residential construction expenditures. 2005 is the base year for this price index. We convert all price indexes for housing to the base year 1987 to ensure consistency.

Table A-4 Fisher Ideal Index for Single Family Residential Construction, 1987-2012.

Year	Index (2005=100)	Year	Index (2005=100)	Year	Index (2005=100)
1987	49.6	1996	66.4	2005	100.0
1988	51.6	1997	68.4	2006	106.2
1989	53.7	1998	70.2	2007	107.2
1990	55.4	1999	73.3	2008	104.1
1991	55.9	2000	76.7	2009	99.5
1992	57.0	2001	80.2	2010	98.0
1993	59.8	2002	82.1	2011	98.7
1994	62.5	2003	86.1	2012	99.7
1995	65.2	2004	93.0		

Source: Census Bureau web page on Construction Price Indexes. 2005 = 100.0.

Single family constant quality construction price indexes.

The Census Bureau also reports price indexes for single family construction using a constant quality of houses, namely the specific characteristics of new houses actually produced in a particular year. We utilize a version of these data which reports both the average sales price of houses actually sold and the average sales price of the typical 1996 house. The information on a 1996 base is obtained from previous versions of the Census Bureau web page on Construction Price Indexes.

Since the constant quality index considers price trends for houses in a fixed base year, it is a Laspeyres index rather than the Fisher Ideal Index summarized in Table A-4. Table A-5 lists the average price of all houses and the price of houses with fixed 1996 characteristics. Dividing the average price of all houses by the price of houses with fixed 1996 characteristics, we obtain a measure of the quality improvement in new single family homes. Figure 1 includes a line representing this quality improvement index.

Table A-5 Average Prices of All Single Family New Houses, and Price of Houses with Fixed 1996 Characteristics, 1987-2007, in dollars.

Year	Average Sales Price of Houses Actually Sold	Average Price of Houses with 1996 Characteristics
1987	\$127,200	\$128,800
1988	\$138,300	\$133,600
1989	\$148,800	\$138,900
1990	\$149,800	\$141,600
1991	\$147,200	\$143,400
1992	\$144,100	\$145,300
1993	\$147,700	\$151,600
1994	\$154,500	\$158,900
1995	\$158,700	\$163,400
1996	\$166,400	\$166,400
1997	\$176,200	\$171,200
1998	\$181,900	\$175,600
1999	\$195,600	\$184,200
2000	\$207,000	\$192,000
2001	\$213,200	\$198,800
2002	\$228,700	\$207,700
2003	\$246,300	\$219,500
2004	\$274,500	\$236,100
2005	\$297,000	\$254,800
2006	\$305,900	\$264,900
2007	\$311,600	\$266,400

Source: Prior versions of the Census Bureau web page on Construction Price Indexes.

Multiple family residential construction deflator.

de Leeuw (1993) introduced the output deflator used for multiple family residential construction. Like the single family deflator, the multiple family deflator is a hedonic index. The index corrects for such characteristics as square feet per unit, the number of units in the project, bathrooms, bedrooms, the presence of parking structures, air conditioning, and certain geographic variables.

We obtain values of the de Leeuw deflator from Table 5.4.4 of the National Income and Product Accounts, which reports information on Price Indexes for Private Fixed Investment in Structures by Type. We use the row entitled Residential Multiple Family Structures. As is the case with all the deflators, this series is converted to represent an index value of 100.0 in the base year 1987. Table A-6 reports the specific value of the multiple family output price deflator in each relevant year.

Table A-6 Price Index for Residential Multifamily Structures (2009 = 100.0).

NAICS	Index (2009 = 100)	NAICS	Index (2009 = 100)	NAICS	Index (2009 = 100)
1987	46.623	1996	53.626	2005	82.631
1988	47.866	1997	56.043	2006	91.645
1989	48.000	1998	60.866	2007	95.975
1990	47.486	1999	62.957	2008	98.839
1991	48.488	2000	65.959	2009	100.000
1992	49.320	2001	67.798	2010	102.451
1993	50.402	2002	70.024	2011	100.473
1994	50.917	2003	72.705	2012	102.616
1995	52.188	2004	76.744		

Source: BEA, National Income and Product Accounts, Table 5.4.4.

Highway, street, and bridge construction.

Table B-1 in Appendix B reports values for the National Highway Construction Cost Index from 2003 to 2010. FHWA reports these index values quarterly; we use the arithmetic average of the four quarterly values to calculate the overall index for each year. (Since the NHCCI begins only in 2003, we use the older Bid Price Index to determine price increases between 2002 and 2003. The Bid Price Index was 147.9 in 2002 and 149.8 in 2003.

Interpolation of Output between Census Years.

The central output measures discussed above refer to Census years. Once these data have been obtained, we interpolate in intervening years using information from another series, the annual Value of Construction Put in Place data. The Census provides the Value of Construction data in classifications which are not expressed in terms of NAICS industries, and there is no established concordance between the Value in Place data and the NAICS industries described in the Census of Construction. Despite these limitations, we select the closest analogue from the Value of Construction data and assign this to each of the industries we are considering.

For single family and multiple family residential construction, we obtain information from the Construction Spending web page of the Census Bureau. From this page, we select Historical Data, and then, from the Historical Value Put in Place category, we select Private. This provides a table on Annual Value of Private Construction Put in Place. From this table, under the category Residential, we select annual information on Private Residential Expenditures in both the new single-family and new multiple family categories. These two series are used to interpolate output between Census years in each of these categories.

For information on annual expenditures on highways, streets, and bridges, we return to the Census Construction Spending Page and to the Historical Data option. This time, we select Total data,

and from the table on Annual Value of Construction Put in Place, under the category Public, we select the Highway and Street expenditures series. This is the series used to interpolate highway expenditures between Census years.

Once we have obtained annual information on output in the relevant category for every year from the Value Put in Place series, we calculate the ratio of the value of output from the Census of Construction to the value of the selected Value Put in Place proxy for each of two adjoining Census years. We then interpolate this proportion linearly. Given the appropriate ratio, we multiply the annual Value Put in Place data by the interpolated ratio to estimate output in each year. More specifically, for years in which there are five years between Censuses, the current procedure is:

$$\left(\frac{\widehat{Census}}{ValuePutinPlace}\right)_x = \left(\frac{Census}{ValuePutinPlace}\right)_{Censusyear1} + \frac{x}{5} \left\{ \left(\frac{Census}{ValuePutinPlace}\right)_{Censusyear2} - \left(\frac{Census}{ValuePutinPlace}\right)_{Censusyear1} \right\}$$

$$x = 1,2,3,4$$

Once the ratio of Census of Construction output to Value Put in Place is estimated for each year, then:

$$\widehat{Census}_x = \left(\frac{\widehat{Census}}{ValuePutinPlace}\right)_x ValuePutinPlace_x$$

that is the estimated value of construction output in any year x is determined by taking the estimated ratio of Census of Construction output to Value Put in Place output for that year, and multiplying by the actual Value Put in Place output observed in that year.

Measures of Labor Input.

Labor input consists of the hours of paid employees plus the hours of self-employed workers, such as partners and proprietors. We describe the calculations used to produce each of these elements of labor input in turn.

Paid Employees.

The main measure of the number of paid employees in each industry in construction is obtained from the Census of Construction. The 2007 Census of Construction reports employment in each construction industry in Table ECO72311. The 1987 and 1992 Censuses of Construction were conducted on a Standard Industrial Classification (SIC) basis, while 1997 was reported on a 1997 NAICS basis. We used the Paid Employment conversion ratios listed in the 1997 and 2002 Economic Censuses to convert the data into a consistent series which corrected for both the change from SIC to NAICS and for subsequent changes in the NAICS. In addition to total employment, we also collected corresponding measures of the number of construction workers and of the number of other workers in each industry.

For intervening years between the Census of Construction, we interpolate employment on the basis of annual data on employment obtained from Current Employment Statistics.⁸⁷ CES also provides corresponding information on production worker employment. The method of interpolation is quite similar to that conducted for output, and is discussed below.

As was the case for output, employment data for NAICS 236117, operative builders, has to be allocated to single and multiple family residential construction. The employment ratios listed in Table A-3 are used for this purpose. The data on residential construction illustrate how information from the Census of Construction and the Current Employment Statistics can diverge. For example, in Figure A1, in residential construction in general, NAICS 2361, the 2002 Census of Construction reported almost as many establishments as the CES. However, in NAICS 236115, single family construction, the CES had many more establishments. Conversely, in NAICS 236117, operative builders, the Census of Construction had more establishments than the CES. Fortunately, in this case the differences became more minor once operative builders were allocated to single or multiple family construction.

⁸⁷ As remarked in the text of our paper, the Census of Construction is selected as the primary source of information on labor input because the Census data on employment are consistent with Census output data.

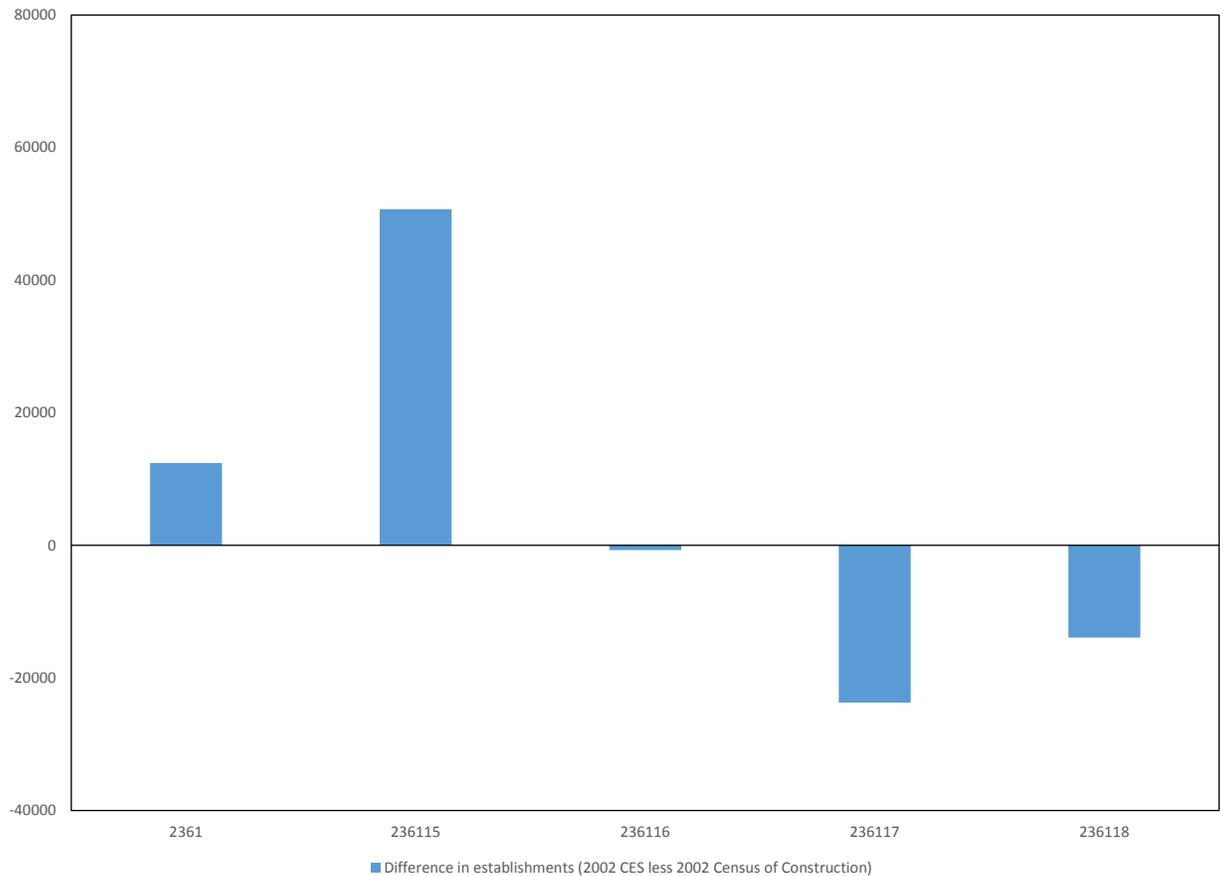


Figure A1: Number of establishments in 2002 CES less the number of establishments in 2002 Census of Construction

Hours of paid employees.

From 2007 onwards, Current Employment Statistics reports information on the average number of hours for both all employees and for production workers. Since we also know the number of employees in each category, average weekly hours of nonproduction workers can simply be calculated as:

$$AWH_{NPW} = [(Employees * AWH_{EMP}) - (Production Workers * AWH_{PW})] / Nonprod Workers$$

AWH represents average weekly hours for non-production workers (NPW), all employees (EMP), and production workers (PW) respectively. Clearly, it is a simple matter to determine average weekly hours for each group from the available data.

Prior to 2007 Current Employment Statistics reported average weekly hours for production workers, but not for total employees. The only information on hours of nonproduction workers comes from the Current Population Survey, from which the Division of Industry Productivity Studies has

calculated the ratio of nonproduction average weekly hours to production worker average weekly hours. This information is available annually. However, it refers only to total construction; no further industry detail is available. Using this information we first estimate nonproduction worker hours in each construction industry i in each year prior to 2007 from:

$$\frac{NPAWH_{i,t}}{NPAWH_{i,07}} = \frac{PWAH_{i,t}}{PWAH_{i,07}} \frac{CPS_t}{CPS_{07}}$$

in which average weekly hours of nonproduction workers in industry i change from their 2007 level either because average weekly hours of production workers in industry i change or the overall ratio of nonproduction worker hours to production worker hours, obtained from the CPS as one single annual measure for all of construction in year t , changes. Finally, measures created through the method described above have a discontinuity between the years of 2006 and 2007, so we benchmark the series on average weekly hours of nonproduction workers to its 2007 level, and chain the proposed index backwards.⁸⁸ Once average weekly hours are known, we multiply the number of workers times average weekly hours times 52 weeks to find total hours worked in each year.

Number of partners and proprietors.

The main source of information on the number of self-employed workers in each industry is the data on partners and proprietors (P&Ps) published in the Census of Construction. Each Census year, the Census of Construction provides, in the Subject Series, a volume on Legal Form of Organization and Type of Operation. These volumes report the number of establishments with partners or proprietors, with separate reports for those establishments with and without payroll. This information forms the basis for our measures of the number of partners and proprietors in each industry. Note that these measures of self-employment are fully consistent with our measures of paid employment and of output, since all three series are drawn directly from the Census of Construction.

In calculating self-employment, we count the number of self-employed individuals as the number of establishments run by proprietors plus the number of establishments operated by partnerships multiplied by the number of partners per partnership. The Internal Revenue Service Statistics of Income, Tax Stats, Partnership Statistics by Sector or Industry, Table 1, provides information on the number of partners per partnership in construction. The data show that in construction there are approximately 2.9 partners per partnership, although the specific value differs somewhat across years.

In the 1987 and 1992 Censuses of Construction, Table 1 of the Subject Report on Legal Form of Organization lists the number of establishments run by partners and proprietors separately for

⁸⁸ A discontinuity occurs because in 2007 we have actual information on weekly hours for nonproduction workers in each industry, whereas in 2006 and prior years we only have estimates of average weekly nonproduction hours as predicted from production worker hours and the nonproduction worker/production worker hours ratio for all of construction. By linking to the 2007 value and chaining for previous years we allow for industry differences in the length of the nonproduction worker work week, as observed in the 2007 data. The linkage procedure builds these industry differences into the data base for earlier years.

establishments with and without payroll. However, Table 1 provides detail only at the three-digit level of the SIC. Table 2 reports further industry detail, but only for establishments with payroll. Therefore, in 1987 and 1992 we allocate the three-digit information on P&Ps by assuming that the same proportions already available for those establishments with payroll also hold true for establishments without payroll. With this allocation procedure, and with adjustments to the NAICS industry definitions similar to those discussed above, we have complete data on the number of partners and proprietors in each industry in each Census year.⁸⁹

The next task is to determine partner and proprietor employment for each year between Census years. The Census Bureau Non-Employer Statistics series provides such information annually beginning in 1997, but only for four-digit NAICS industries. We use the Non-Employer Statistics annual data on partners and on proprietors to allocate P&P self-employment between 1997 and 2011. Prior to 1997, the Non-Employer data are not available. Therefore, between the 1987 and 1992 Censuses, and the 1992 and 1997 Censuses, we benchmark self-employment to the corresponding series for paid employees in each industry.

Partner and proprietor hours.

The only source of information on average weekly hours of partners and proprietors in construction is the Current Population Survey. The CPS provides no detail on individual industries in construction, but simply reports average weekly hours of partners and proprietors for all of construction.⁹⁰ We assume that the CPS data on average weekly hours of partners and proprietors can directly be applied to each individual industry within construction. Multiplying the number of P&P by their average weekly hours times 52 provides the total number of hours worked by self-employed workers within each industry in construction during every year.

Total Hours and Labor Productivity.

Once we have calculated total hours for both paid employees and partners and proprietors we add the two types of labor together to obtain a measure of the total hours utilized in each industry in each year. The number of hours is converted to index form with the value of 100.00 in the base year 1987. Output measures are similarly converted to index form with the base year 1987. We then divide the output index by the index of total hours to obtain comparable index values of output per hour, or labor productivity, within each industry in each year.

Interpolating Estimates of Labor Inputs between Census Years.

⁸⁹ When NAICS industries change, or when operative builders are allocated to single and multiple family residential construction, we consistently use the employment bridges to assign partners and proprietors to the appropriate industry.

⁹⁰ From 1982 to 1984 the CPS briefly reported information on P&P average weekly hours in several different fields of construction. These data are not a sufficient basis to develop measures of P&P hours for the different industries in construction.

The last topic to be discussed in this data section is the interpolation of labor inputs between Census years. Current Employment Statistics provides annual data on the number of employees and the number of production workers in each detailed construction industry for each year from 1987 forwards. We create benchmark ratios by calculating the ratio of Census employees to CES employees in each Census year. These ratios are interpolated linearly between each pair of adjacent Census years. Once the appropriate Census/CES employment ratio has been determined, we multiply this by CES employment in each year to obtain an employment series consistent with the Census data. A similar benchmarking technique is used to distribute Census construction workers to individual industries in each intervening year in proportion to CES data on the number of production workers in each detailed construction industry. The specific equations used to interpolate labor input in each intervening year are similar to those described in the discussion of output above.

Appendix B. NHCCI deflator and PPI deflator (BHWY) for NAICS 23731, Highway, Street, and Bridge Construction.

Table B-1 NHCCI Index and BLS PPI values for Highway, Street, and Bridge Construction.

NHCCI deflator. An output price deflator.

Year	Quarter	NHCCI Index (March 2003 = 1)	Year	Quarter	NHCCI Index (March 2003 = 1)
2003	March	1.0000	2008	March	1.2500
	June	1.0156		June	1.2938
	September	1.0038		September	1.3521
	December	0.9929		December	1.2835
2004	March	1.0260	2009	March	1.1818
	June	1.0638		June	1.0901
	September	1.0849		September	1.0752
	December	1.0910		December	1.0410
2005	March	1.1189	2010	March	1.0683
	June	1.1489		June	1.0671
	September	1.2045		September	1.0595
	December	1.2429		December	1.0520
2006	March	1.2727	2011	March	1.0524
	June	1.3464		June	1.0691
	September	1.4084		September	1.0817
	December	1.3693		December	1.0880
2007	March	1.3425	2012	March	1.1147
	June	1.3118		June	1.1468
	September	1.2691		September	1.1315
	December	1.2363		December	1.1148

BLS PPI deflator (NDUBHWY--BHWY--). A discontinued input-cost based deflator, Series ID: NDUBHWY--BHWY--. The BLS deflator is benchmarked to 1.0000 in March 2003, in order to make comparisons with the NHCCI deflator easier.

Year	Mar	Jun	Sep	Dec
2000	1.000	1.012	1.021	1.010
2001	1.010	1.021	1.018	0.974
2002	0.976	0.985	0.988	0.983
2003	1.006	1.007	1.006	1.009
2004	1.048	1.081	1.116	1.118
2005	1.179	1.204	1.295	1.275
2006	1.319	1.400	1.367	1.354
2007	1.397	1.447	1.452	1.490
2008	1.572	1.724	1.773	1.482
2009	1.457	1.535	1.530	1.539
2010	1.581	1.596		

Unemployment Rate for Construction Workers.

From Current Population Survey, Series ID: LNU04032231

Year	Mar	Jun	Sep	Dec	Annual
2000	8.7	4.6	4.6	6.8	6.2
2001	8.4	5.1	5.5	9.0	7.1
2002	11.8	6.9	7.0	10.9	9.2
2003	11.8	7.9	7.6	9.3	9.3
2004	11.3	7.0	6.8	9.5	8.4
2005	10.3	5.7	5.7	8.2	7.4
2006	8.5	5.6	5.6	6.9	6.7
2007	9.0	5.9	5.8	9.4	7.4
2008	12.0	8.2	9.9	15.3	10.6
2009	21.1	17.4	17.1	22.7	19.0
2010	24.9	20.1	17.2	20.7	20.6
2011	20.0	15.6	13.3	16.0	16.4
2012	17.2	12.8	11.9	13.5	13.9
2013	14.7	9.8	8.5	11.4	11.3

Pieper (1991, p. 246) remarks that price indexes tend to rise more quickly than cost indexes during an economic expansion, but drop more quickly than cost indexes in contractions. In the construction of highways, streets, and bridges industry, the NHCCI price deflator increases at approximately the same rate as the BLS PPI cost deflator during the 2002 to 2006 expansion. However, during the severe downturn which occurred in 2007, and in subsequent years, the NHCCI price deflator fell much more sharply than the PPI cost deflator. Such discrepancies illustrate the need for a much broader range of price deflators in construction.

Appendix C How the Census Bureau Prepares the Single Family Residential Construction Deflator.

Appendix C provides a brief outline of how the U.S. Census Bureau calculates the single family residential construction price deflator, which is one of the main elements used to measure growth in labor productivity in single family construction, as described in Section II above. Musgrave (1969) reported early Census work on this topic, which was conducted at an admirably early stage well before price indexes incorporating quality improvements were widely adopted in the economics literature. The Census Bureau web page on Construction Price Indexes provides much further detail on how the single family deflator is determined; Musgrave's early efforts have been modified in some respects.⁹¹ Appendix C is intended to provide readers with an intuitive understanding of how the Census currently prepares the single family residential construction price deflator.

The central data are obtained from individual houses which have been selected for inclusion in the Survey of Construction. The Survey selects houses for inclusion through a multiple stage sampling process, which first selects a location which issues building permits and then selects specific residential building units in each area chosen. In addition, a small number of individual houses is included to represent areas which do not grant permits. The Survey of Construction collects information on the value of individual houses (the sale price or contract price), the market value of the lot, and many specific characteristics of each house.

Different portions of the Census analysis use slightly different variables. However, a typical regression might well include the following types of independent variables:

- Square feet of house (floor area), measured in logarithmic form as log(square feet).
- Metropolitan area location. (Yes or No).
- Number of bedrooms.
 - (Less than three bedrooms
 - Three bedrooms
 - More than three bedrooms)
- Number of bathrooms.
 - (Less than two bathrooms
 - Two or Two and one-half bathrooms
 - Three or more bathrooms)
- Number of fireplaces.
 - (No fireplaces
 - One fireplace
 - Two or more fireplaces)
- Garage
 - (No garage

⁹¹ In particular, the Census Bureau now subtracts the value of the site and certain non-construction costs from the sales price and floor area (square footage) is expressed as a continuous variable rather than as nine categories.

One or two-car garage
 Three or more car garage)
 Basement
 (No basement
 Basement)
 Geographic Location
 The nine Census Divisions (New England, Middle Atlantic, East North Central, West North
 Central, South Atlantic, East South Central, West South Central, Mountain, Pacific)
 Also separately:
 Florida
 Arizona and Nevada
 California and Hawaii

This set of independent variables, or in practice a broader more inclusive set of variables, is then used to explain the value of the house under construction, essentially the selling price less the value of the lot and of non-construction costs.⁹² The sales price, as well as the square foot floor space, is typically measured in logarithmic terms. Once regressions of this type are calculated, the results provide a measure of how much each of these characteristics is associated with the observed sale price of houses. Importantly, such regression results provide a way of correcting for the changing characteristics of houses. If, over time, a greater proportion of houses have more floor space or three or more garages, the empirical coefficients associated with each of these features provide a natural way to translate the greater prevalence of such features into more house rather than just higher house prices.

This method of adjusting for observed characteristics is called hedonic adjustment because each feature is presumed to have value or utility (hence hedonism) for consumers. The regression described above can be summarized compactly as:

$$ConPrice_j = C_{i,j} \hat{\beta}_i \quad (C.1)$$

in which $ConPrice_j$ is the construction price of house j , $C_{i,j}$ is each characteristic i in house j , and $\hat{\beta}_i$ is the observed regression coefficient for characteristic i . $C_{i,j}$ also includes a constant term. Similar, but separate, regressions can be prepared for each year t . The hedonic model views each house as the sum of its relevant characteristics. For example, house 1 can be viewed as the sum of its i particular characteristics, $C_{i,1}$.

We now turn to the issue of how regressions based on such hedonic characteristics can be converted into price indexes. The first point is that the characteristics for house 1 and for any other house are readily available from the $C_{i,j}$ matrix. These data on characteristics form the basis for a

⁹² By subtracting lot price or other non-construction costs from sale value, the analyst essentially assumes that lot value is separable from (can be analyzed independently from) the amount of construction output. For an example of tests of separability, see Berndt and Wood (1975). (To be more precise, subtracting lot value from overall property value assumes that lot value is additive to structure value, which is a stronger form of separability.)

measure of the quantity of output embodied in each house, $q_{i,j}$. However, these measures of quantity have to be supplemented by measures of price to determine how a single index of output is created from these disparate elements of output. Initially, no information is available on the price of each characteristic, such as the price for a garage for a third car. The price of each characteristic i , p_i , is therefore instead inferred from the corresponding regression coefficient, $\hat{\beta}_i$. Once the price and quantity of each characteristic, p_i and $q_{i,j}$, have both been established, it is possible to proceed with determining price indexes through standard procedures.⁹³

As with other price indexes it is possible to define a Laspeyres Price Index in terms of the market basket observed in any given base year. The Laspeyres index indicates the change over time in houses which have the same mix of characteristics observed in the base year, currently 2005. A Paasche index shows the price of houses with the same characteristics observed in the most recent year; the Paasche index constantly adjusts as the relevant mix of houses changes from year to year.

The Laspeyres index for house prices can be expressed as:

$$\text{Laspeyres Price Index} = \frac{\sum_i (p_{t,i} * q_{0,i})}{\sum_i (p_{0,i} * q_{0,i})} \quad (\text{C.2})$$

in which $p_{t,i}$ is now the price of characteristic i in year t and $p_{0,i}$ is similarly the price of characteristic i in the base year 0. $q_{0,i}$ is the corresponding quantity of characteristic i in year 0, and can be understood as the total bundle of characteristics for all houses or, equivalently, as the features of an average house. The Laspeyres Price Index describes how the price of houses with characteristics fixed in the base year, $q_{0,i}$, increases over time. The Census now uses a base year of 2005. The Laspeyres Price Index therefore currently shows how much the price of houses characteristic of 2005 increases over time. The third column of Table A-5 in Appendix A above reports how much the price of houses with fixed 1996 characteristics increased over time. Finally, note that the denominator of expression C.2 indicates the total value of houses in the base year 0. By dividing expression C.2 by the number of houses, the price index can express the average price of houses in terms of the proportion of houses falling into each of the independent variables categories.⁹⁴

⁹³ In practice, the Census Bureau calculates five separate regression equations. Four regressions report the characteristics and value of detached houses within four broad Census geographic areas, the Northeast, the Midwest, the South, and the West. The fifth equation refers to attached single-family homes throughout the country.

⁹⁴ For example, in the Northeast equation 37.1 percent of houses have zero fireplaces, 56.5 percent have one fireplace, and 6.4 percent have two or more fireplaces. One can view such patterns as the total distribution of characteristics in the overall marketplace, or as an average house which falls into the zero fireplace category in 0.371 of all cases, in the one fireplace category 0.565 of the time, and in the two fireplace category 0.064 of the time.

Conversely, the Paasche price index is expressed in terms of the house characteristics observed in the present year, $q_{n,i}$. Of course, the Paasche is slightly more complex to calculate because the market basket of characteristics to be examined constantly changes over time. Specifically:

$$\text{Paasche Price Index} = \frac{\sum_i (p_{t,i} * q_{n,i})}{\sum_i (p_{0,i} * q_{n,i})} \quad (\text{C.3})$$

where $q_{n,i}$ shows the quantity of each characteristic i observed in year n .

Finally, as usual the Fisher Ideal Index is defined as:

$$\text{Fisher Ideal Index} = (\text{Laspeyres Price Index} * \text{Paasche Price Index})^{1/2} \quad (\text{C.4})$$

We use the Fisher Ideal Index, which BEA has generally adopted as the relevant single family residential construction deflator. Specific values of the price index used are listed in Table A-4 of Appendix A. For much further information on these matters see the Census Bureau web page on Construction Price Indexes.